AN OPERATIONAL MODEL FOR FINITE STATE MACHINE REPLANNING IN MODSAF

by

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ABSTRACT

The United States Army is tasked by the nation to provide an army that is disciplined, well trained, well-equipped, and well-led, capable of deploying anywhere in the world and winning decisively. At the tactical level of war, this translates to individual commanders preparing their units to fight and defeat an enemy. In order to prepare to accomplish this task, commanders must train their units under realistic conditions. Given the fiscal constraints placed on the United States military, simulations provide an opportunity for leaders to utilize current training methodology to train themselves and their staffs for wartime missions at minimum cost.

An essential component of a simulation is the Computer-Generated Force (CGF) that attempts to replicate realistic human and physical behaviors in the synthetic battlefield. Although there are many different CGFs in existence today, this thesis will focus on how ModSAF replicates and implements human behavior. Currently, there is no organic behavioral model in ModSAF that conducts self-modification of tasks based purely on observation of the synthetic battlefield. Existing models are adequate to train perfunctory, rote tasks but do not challenge military leaders under conditions that are found during combat. A human operator sitting at a computer workstation is necessary to make behavioral decisions for subordinate computer generated entities. This does not represent how a military leader would conduct these tasks in a live tactical situation. This thesis will propose an operational model for ModSAF that will allow a

tank platoon to autonomously replan its behavior based on observation of its synthetic battlespace.

ACKNOWLEDGEMENTS

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While the members of my thesis committee assisted me tremendously, I would be remiss not to recognize those closest to my heart. My dad Dr. Richard F. Kolasheski kept my research and me on track throughout the entire process. Your are a great inspiration. My brother-in-law Captain Chris Norrie was invaluable in ensuring that the tactical portion of this thesis was valid and for offering a helping hand when it came to editing my work. Finally, I want to acknowledge my wife Buffy and daughter Kelli who provided me the flexibility to concentrate and prioritize my efforts. Your love and patience were instrumental in this research project's fulfillment. I love you both dearly. To all these people, I owe thanks and great gratitude.

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CHAPTER 1

ARMY SIMULATION

1.1 Introduction

"Everything in war is simple, but the simplest thing is difficult. The difficulties accumulate and end by producing a kind of friction that is inconceivable unless one has experienced war."

-Carl von Clausewitz

The United States Army exists to support and defend the Constitution of the United States against all enemies foreign and domestic. It accomplishes this by providing military units that are disciplined, well trained, well equipped, and well-led, capable of deploying anywhere in the world and achieving decisive victory. At the tactical level of war, this translates to individual commanders preparing their forces to fight and defeat an enemy. In order to accomplish this task, a commander must successfully visualize the battlefield; create a simple battle plan that can be executed by his subordinates; execute the plan; and make any necessary refinements or adjustments to the plan as the battle evolves. He must be involved and provide effective Command and Control (C2) over his unit in what is a very dynamic, complex environment. It is the commander's responsibility alone to ensure that his force is prepared to fight.

Simulations have been a topic of interest to military leaders for some time. Given the fiscal constraints that are placed on the United States military, simulations provide a good vehicle to train leaders and their staffs for their wartime mission at minimum cost. An essential component of a simulation is the Computer-Generated Force (CGF) that attempts to replicate realistic human and physical behaviors.

1.11 The Nature of War

War is a violent clash of interests between or among organized groups, characterized by the use of military force. Each group has the ability to generate violence in an organized fashion and in sufficient scale as to reach a desired end state. Each group is a complex system that has numerous individual parts that must cooperate with each other in order to be victorious. The essence of war is a violent struggle or clash between two hostile and independent wills that are each trying to impose their will and way of life on one another. It is not governed by the actions or decisions of a single individual, but is a result of the collective behavior of all the individual parts of the system interacting within their environment. The United States Marine Corps describes the environment of war as being complex where uncertainty, friction, and disorder encroach upon it. (Marine Corps Doctrinal Publication, *Warfighting*, 1997)

Since the very nature of war creates conditions ripe with uncertainty, friction, and a natural type of disorder, military planners must try to determine probabilistic courses of action that an enemy might take and plan appropriately. Unfortunately, seldom are they 100% correct. Plans will fail, instructions will be misunderstood, and humans will make mistakes each adding to the battle's complexity. A successful commander must try to restore some semblance of order to this environment,

influencing the general flow of action on the battlefield rather than trying to control every event. Advances in technology can help a commander be successful and gain an advantage over one's enemy, but these same advances can add a new level of complexity. (Marine Corps Doctrinal Publication, *Warfighting*, 1997)

Today's commanders are responsible for a larger portion of the battlefield than in previous years because of advances in both weapon system range and lethality. This equates to individual fighting vehicles dispersed at great distances, stretching the limits of positive control that a commander can exert in his area of operations. An area of operation is a geographical area assigned to a commander for which they have responsibility and in which they have authority to conduct military operations (FM 100-5). Additionally, greater dispersion can create gaps or unoccupied areas in a commander's coverage that an enemy can exploit. Enemy exploitation can blur the distinction between friend and foe and further complicate the battlefield.

1.12 Simulation Use in the Army

The United States Army must use simulations to help it meet the expectations placed upon it by the American people. The Department of Defense (DOD) defines the term simulation as "a model that represents activities and interactions over time. A simulation may be fully automated (i.e., it executes without human intervention), or it may be interactive or interruptible (i.e., the user may intervene during execution). A simulation is an operating representation of selected features of real-world or hypothetical events and processes. It is conducted in accordance with known or assumed procedures and data, and with the aid of methods and equipment ranging

from the simplest to the most sophisticated." (Simulation Handbook for Commanders, 1999) The Army recognizes five types of simulations:

1) Research and development simulations which support the design and development of new weapon and equipment systems;
2) Production and logistic simulations which support the Army's determination of logistics requirements, system productivity assessments, and industry based appraisals;
3) Test and evaluation simulations which assist the Army in the material acquisition process;
4) Analysis simulations which are simulations used in the support of operations and combat development;
5) Education and training simulations which teach leaders and soldiers concepts and skills.

These simulations support the Training, Exercises, and Military Operations (TEMO), Advanced Concepts Requirements (ACR), and Research, Development, and Acquisition (RDA) domains. This research will concentrate on education and training simulations and how they are used in the TEMO domain.

1.13 Army Training Strategy

The Army's strategy is to use simulations to help train soldiers and test systems. This does not mean that the Army has adopted a policy mandating the exclusive use of simulations to accomplish training objectives. Rather, it means that the Army advocates using simulations when the advantages they represent are greater in terms of cost, realism, and accessibility for the actual task trained than actually executing the task itself in the field. In the Department of the Army's "Simulation Handbook for Commanders", it describes the move because of fiscal constraints placed on the Army. The Army could no longer afford to move entire units to the field and tie up all the

resources required to train them at the frequency the Army's doctrine prescribed for maintaining readiness. Doctrine is the fundamental principles that guide military forces in the pursuit of its objectives. Gradually, however, advances in simulator and simulation technology made the advantages of using simulation to train apparent. Several of these advantages are:

- affording the organization the ability to exercise and evaluate internal staff training proficiency;
- increasing the organization's awareness of the complexity of the modern battlefield in all environmental conditions without the inherent dangers of live training;
- providing an evaluation of the communication processes within an organization;
- providing feedback on the commander and his staff's ability to respond to unexpected activities or events on the battlefield;
- providing a low cost method for immediate feedback and retraining opportunities;
- and, achieving resource economies by encumbering fewer resources then would be necessary in real time scenario development and execution.

Figure 1-1 illustrates the environment in which the Army must currently prepare its forces for combat and captures the essence of why the Army has moved towards simulation-based training and doctrinal analysis. The arrows pointing towards the center of the figure represent some of the external environmental factors that have influenced the Army's movement to simulation based training. These factors are:

- concern over the safety of the force (Safety);
- concerns for the environment (Environment);
- reduced time available to train (Time);
- lack of available maneuver space-land is at a premium (Public Use);

- concerns over personnel and equipment availability (Money);
- treaties with local and foreign governments restricting range/land use (Treaties).

The small arrows in Figure 1.1 represent the issues the Army must deal with in satisfying its needs to accomplish those things necessary to maintain a trained force.

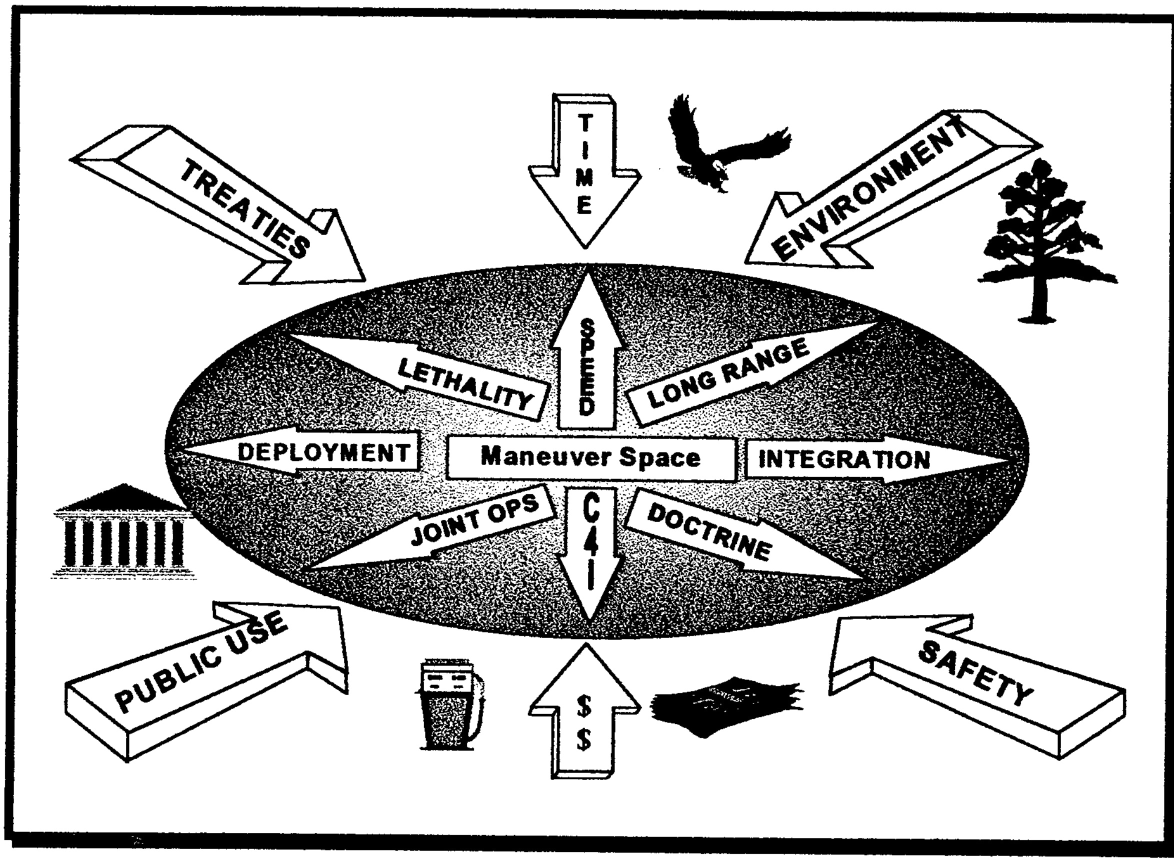

Figure 1.1 Shift to Simulations for Training the Army
(Taken from the Simulation Handbook for Commanders, 1999)

These include:

- a need to maintain weapon system proficiency (Lethality);
- a need to conduct training effectively and efficiently in minimum time (Speed);

- a need to conduct deployment and joint military training (Deployment & Joint Operations Training);
- a need to integrate and train the entire combat team using current Army doctrine (Integration);
- a need to develop the best Tactics, Techniques, and Procedures (TTP) to accomplish wartime missions (Doctrine);
- a need to operate across great distances and at long ranges (Maneuver Space & Long Ranges);
- and, a need to represent Command, Control, Communications, Computers, and Intelligence (C4I) in a realistic setting (C4I).

This equates to soldier participation in realistic, battle-focused training events (both live and simulated) that have mechanisms to assess the skills of the unit to whom the soldier belongs and can allow retraining when applicable.

1.14 Command and Control Training Simulations

According to the National Simulation Center in Fort Leavenworth, Kansas in their handbook titled "Simulation Handbook for Commanders", a C2 training simulation is effective if it can meet these four specific criteria:

- be realistic;
- replicate the conditions on the battlefield to include portraying human behaviors;
- offer free-play which means that both the friendly and enemy force be able to act in a manner that allows them to carry out their mission to the best of their capabilities;
- and, be neutral, acting out the exact decisions and activities that it has been instructed to perform.

Successful C2 simulations that can meet these criteria will effectively bridge the gap between the requirements that the Army places on units to maintain wartime readiness

and the external influences that are affecting the Army. This, in effect, neutralizes the external environmental forces shown in Figure 1.1. Training simulations will create realistic operational and battlefield environments that will train a commander and his staff with maximum results in less time and with fewer resources than traditional methods. If they cannot do this they are of little value. (Simulation Handbook for Commanders, 1999)

A typical battalion level C2 simulation training is normally conducted in the following fashion. The trainees will be the battalion commander and his staff and company commanders will be role players. An Opposing Force (OPFOR) is used to maneuver and fight against the battalion to replicate the realism associated with a military operation. Figure 1.2 depicts the layout for a typical battalion level training simulation exercise. The commander and his staff are located in their normal tactical Command Post (CP) in the field. They are given a mission to execute from their higher

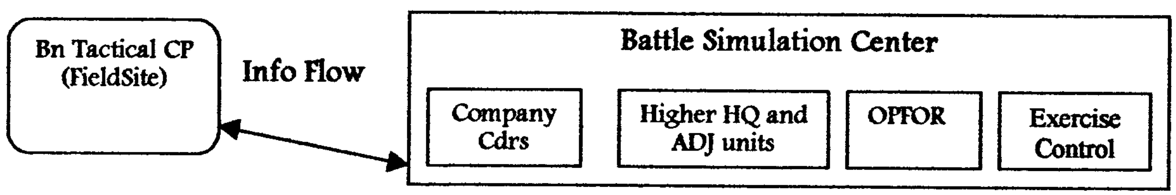

Figure 1.2 Battalion Level Simulation Training Exercise Layout
(Taken from the Simulation Handbook for Commanders, 1999)

headquarters. They plan, coordinate, control, monitor, and execute the mission from a field location. The company commanders, Opposing Force (OPFOR), the battalion's higher headquarters and adjacent units, and exercise controllers operate and perform their duties from computer workstations located in a battle simulation center nearby.

The subordinate commanders, in this case company commander, receive and execute the orders from the battalion commander and his staff. The simulation replicates the intent of these orders based on information that the company commanders input into the system from their computer workstations. Company commanders will monitor operations at their workstation and provide pertinent information on what is happening to the battalion. The battalion commander and staff execute the operation in response to the information that they receive from the company commanders. Many times in C2 training simulations, the company commander is responsible for managing all the activities happening in his organization. He is responsible for planning, coordinating, controlling, executing, monitoring, and replanning missions for all his platoons.

Is this a realistic portrayal of the commands, actions, and responses that would occur in an actual combat situation and are the training results being maximized? To answer this question, we must first understand the functions that real leaders perform in tactical situations and then look at how they are modeled in simulation.

1.2 Battle Command

The ability to visualize the events unfurling on a complex battlefield and then influence the general flow of action on it towards a successful outcome is called battle command. Defined in Field Manual (FM) 100-5, "Battle command is the art of battle decision-making, leading, and motivating soldiers and their organizations into action to accomplish missions. It includes visualizing the current and future state of the battlefield, then formulating concepts of operations to get from one to the other at least cost. It includes assigning missions; prioritizing and allocating resources; selecting the

critical time and place to act; and knowing how and when to make adjustments during the fight." In army terminology, battle command encompasses both command and control which is essential to all-military operations and activities. A leader must employ C2 effectively over his force if he wants to be successful.

The basis for C2 comes from the authority vested in a commander over subordinates by law or through personal influence. FM 100-5 states that the command portion of C2 is the art of motivating and directing leaders and subordinates into mission accomplishment. It means having the ability to see oneself, the terrain, and the enemy in relation to each other and then formulating a military concept of operation to win. It has two vital components, decision-making and leadership. Decision-making is the ability to know when decisions are needed, knowing what to decide, and knowing the consequences of the decision that is made. Leadership as defined by Army doctrine is taking responsibility for decisions; being loyal to subordinates; inspiring and directing assigned forces and resources toward a purposeful end; establishing a teamwork climate that engenders success; demonstrating moral and physical courage in the face of adversity; providing the vision that both focuses and anticipates the future course of events. (FM 100-5) The second portion of C2 is control. It is the process of monitoring an organization's effectiveness, identifying problems, and taking corrective measures when necessary to fix them. Control is where most of the problems a leader faces occur. The basis for these problems comes from the natural friction associated with the dynamic environment of war. Several examples of this friction and the ensuing problems that a leader may encounter are poor weather, poor communications, vehicles that suddenly break down, poor reports from subordinates, and difficult terrain.

Since commanders at the battalion level and higher must plan, direct, coordinate, and control forces and operations in both garrison and tactical environments, they are given a staff to assist them. A battalion is the lowest level Army organization that has a complete staff that provides support to the commander depicted in Figure 1.3. A generic Army battalion staff consists of four functional sections: the personnel section (S1), the intelligence section (S2), the operations and training section (S3), and the logistics section (S4). An executive officer (XO) acts as a second in

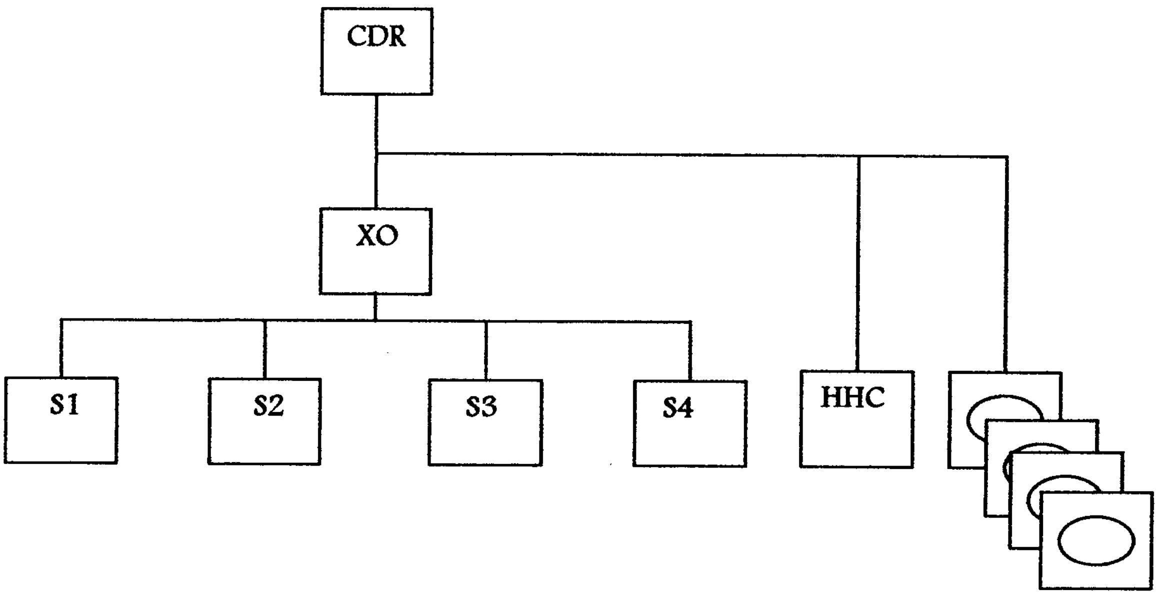

Figure 1.3 Generic Army Battalion Staff with Subordinate Unit Representation

command and is responsible for coordinating the actions of the staff. Additionally, there are four tank companies and a headquarters company found in a heavy armored battalion. The tank companies each consisting of three tank platoons, provide the combat forces for the battalion and the headquarters company provides all logistical support. The staff's primary purpose is to provide timely information to the battalion

commander; information that allows him to make informed decisions. Unfortunately, the staff will not be able to solve all problems that may be encountered by the battalion, but they must find ways to mitigate them.

1.21 Tactical Decision-Making Process

It is important to understand the process that a commander and his staff undergo in preparing and executing tactical missions. Figure 1-4, A Battalion Level Tactical Decision-Making Model, illustrates this process. The ovals represent actions that are taken jointly by the commander and his staff, the rectangles represent actions by either the staff or commander, and the arrows represent information flows. Included in this process is the issuance of the commander's intent. A commander's intent is a concise expression of the purpose of a military operation, its desired end state, and the way in which the accomplishment of that goal will posture the unit for future operations. (FM 101-5-1) The outputs in the decision-making process are an OPORD that is issued to subordinates (company commanders and platoon leaders) and successful mission execution.

An operation order is a directive issued by a commander to subordinate commanders for effecting the coordinated execution of an operation. It is usually a five-paragraph field order, containing a description of the task organization, situation, mission, execution, administrative and logistics support, and command and signal (communications and control matters) for the specified operation. (FM 101-5-1) Upon receipt of the battalion OPORD, subordinate commanders develop their own concept of the operation for the mission that they were assigned and issue an OPORD to

their subordinates. In summary, tactical operations are characterized by centralized planning and decentralized execution.

Unfortunately, the enemy rarely cooperates and unexpected contingencies arise. In a tactical environment when either the staff or commander becomes aware of an unexpected contingency, they immediately begin a replanning process to meet the

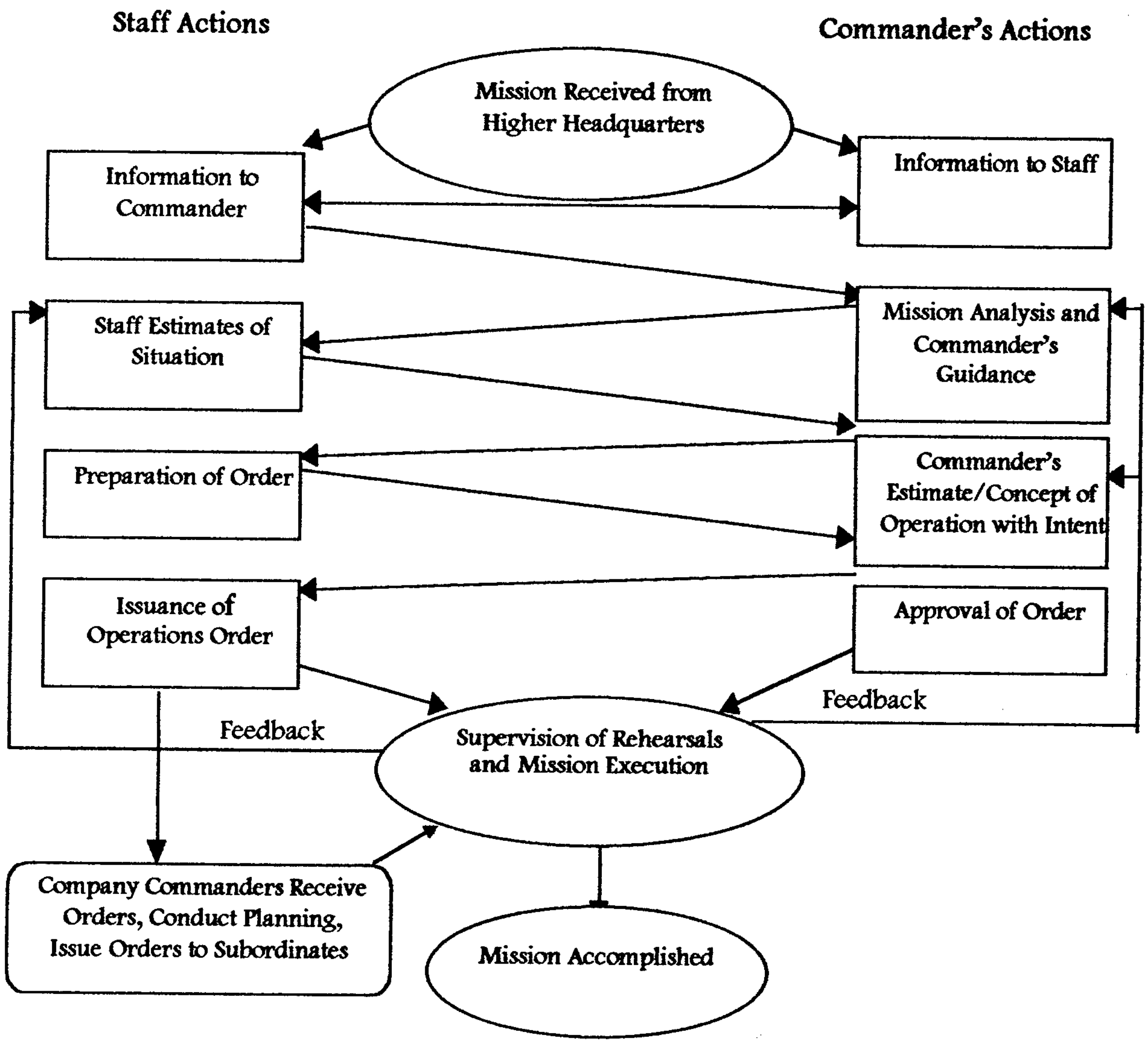

Figure 1.4 Battalion Level Tactical Decision-Making Model (Taken from the Army's Combined Arms and Services Staff School Text on Military Decision-Making, 1990)

contingency. The feedback mechanisms in Figure 1.4 illustrate where in the decision-making process replanning begins. The output of the replanning process is a Fragmentary Order (FRAGO). A FRAGO is a shorter form of an operation order, which contains information of immediate concern to subordinates. It is an oral, digital, or written message that provides brief, specific, and timely instructions. It is issued after an operation order to change or modify that order or to execute a branch or sequel to that order (FM 101-5-1). A subordinate leader that receives a FRAGO from his higher headquarters will conduct his own hasty replanning process. He will assimilate the information contained in the FRAGO that he has received. He will conduct a quick terrain and enemy analysis and assess his own unit's status relative to the new mission. He will select a course of action to take and assign new tasks to subordinates as necessary. He will issue his own FRAGO to his subordinates and the new mission will be executed. Training and Standing Operating Procedure (SOP) enables companies and platoons to execute the tasks contained in FRAGOs successfully during war (FM 17-98). An SOP is a set of instructions covering those features of operations, which lend themselves to a definite or standardized procedure without loss of effectiveness (FM 101-5-1).

Because of the dynamic nature of war, once an operation has begun, the battalion commander and his staff are better equipped to influence the general flow of action on the battlefield rather than trying to control each event. Unexpected contingencies will arise, because of poor communications, casualties, or an uncooperative enemy. This makes it necessary for lower echelon forces to modify their plan for accomplishing a mission without formal guidance or orders from their higher headquarters. They will use initiative; develop an awareness of the battlefield situation;

communicate and interact with adjacent units as applicable; and execute the new plan. Of course, this new plan will stay within the battalion commander's intent for conducting the stated operation. These successful actions at the company, platoon, and section level in battle win wars.

Unfortunately, current simulation training exercises as they are, do not effectively train a battalion staff and its commander to their full potential. This is because commanders are not forced to make decisions based on partial information. Currently in command post training exercises subordinate commanders are able to provide their higher headquarter (battalion) almost perfect real time information on what is happening in their particular area of operations. This does not accurately depict what would happen on a real battlefield. Friction exists at the company command level and below which makes it difficult for subordinate commanders to accurately report their unit's true status. An example might better illustrate this point.

A tank company is currently defending a battle position when a single enemy reconnaissance (recon) vehicle enters the company's area of responsibility vicinity grid 123456. Two tanks from adjacent platoons in the company and different vantage points on the battlefield have line of sight to this enemy vehicle and send a enemy contact report to their platoon leaders. The platoon leaders independently assess their subordinate's report and decide to report the information to their company commander. The company commander receives the reports and then must ascertain whether the platoons are reporting the same enemy vehicle or two separate ones. In simulation, the company commander would know that there is only one vehicle and report appropriately to his higher headquarters never having to take into account any of the friction associated with this example.

1.3 Computer Generated Forces

Many simulations have been developed to train soldiers and assist in the development of new Army doctrine. There are constructive, virtual, and live simulations in use today. Constructive simulations are the preferred method for training a commander and his staff and in analysis of new doctrine. Special software is used to represent units, their behaviors, and associated outcomes in a computer generated battlefield. Real people stimulate the simulation, but are not involved in the outcome.

An essential component of constructive simulations is the Semi-Automated Force (SAF). One technique for replicating this force is to use a computer system that generates and controls multiple simulation entities using specialized software and a human operator. The type of force that is created in this system is a Computer-Generated Force (CGF) or Semi-Automated Force (SAF). A CGF system is programmed to behave according to the tactical doctrine of the force that it is replicating. It provides a credible representation of the battlefield, to include behavioral, physical, and environmental models. The majority of these type CGF systems replicate all seven Battlefield Operating Systems (BOS) maneuver, air defense, artillery, intelligence, mobility and survivability, combat service support, and command and control. The BOS are the major functions that an army must perform on the battlefield in order to be successful.

The individual entities controlled by a CGF system exist in a simulated subset of the real world. They obey the laws of physics relevant to the function and tasks that they represent. Likewise, combat interactions by CGF are modeled in accordance with the physics that are appropriate to the weapon systems involved in the interchange.

CGF systems have built-in behaviors. These behaviors allow entities to react autonomously to events unfolding on the simulated battlefield or to orders given to them by a human operator. All behaviors are encoded as production rules, algorithms, or formal behavior specifications that attempt to replicate realistic human and physical behaviors. (Petty, 1996)

1.31 Semi-Automated Forces used in Simulation Based Training

There are many different types of CGF and SAF systems in existence today. The U.S. Army, however, predominantly uses two systems to conduct its simulation-based training. These two systems are the Close Combat Tactical Trainer (CCTT) SAF and Modular Semi-Automated Forces (ModSAF). Both of these CGF systems are analyzed extensively in this paper. Beginning in 2004, the Department of Defense is scheduled to release its next generation CGF, ONESAF. ONESAF is a composable CGF that will represent a full range of operations and control processes from individual entity level up to battalion. It will be capable of supporting all Modeling and Simulation (M&S) domain applications (ACR, RDA, and TEMO) with special emphasis on both human-in-the loop and no human in the loop simulation. ONESAF will integrate the ModSAF application baseline with the functionality of CCTT SAF. (Simulation, Training, and Instrumentation Command (STRICOM) Combined Arms Tactical Trainer's Web site)

1.32 CCTT SAF Overview

CCTT SAF is a critical component of the U.S. Army's Close Combat Tactical Trainer that is used to train armor and mechanized infantry units up through Battalion/Task Force level on their wartime missions. The CCTT system is a fully

Distributed Interactive Simulation (DIS) compliant training system that consists of networked vehicle simulator manned-modules capable of interacting with each other and computer generated forces. The CCTT SAF is the system responsible for populating the synthetic battlefield with these computer controlled friendly and enemy forces.

There are two main software components in the CCTT SAF: the SAF workstation and the CGF simulator. The SAF workstation is the operator interface that allows an operator to control the computer-generated entities on the synthetic battlefield. Separate SAF workstations are required to control friendly and enemy forces. The CGF simulator is responsible for defining entity dynamics as well as the behavioral simulation of these entities. The tactical behaviors employed by CCTT entities are governed by Combat Instruction Sets (CISs). A CIS is a natural language description of tactical behavior that is founded on U.S. military doctrine. A CIS contains a behavior description, initial and terminating conditions, input data, and situational interrupts. CISs are implemented as Finite State Machines (FSMs) in Ada. CISs can be tailored to a particular unit type such as an U.S. Army tank platoon. Unfortunately, the structure of CCTT SAF FSMs restricts the operator from responding to changes in orders once a task is running. (Kraus, Franceschini, et al., 1996)

1.33 ModSAF Overview

ModSAF is a constructive, DIS system that was developed to assist the Army in training, combat development, experiments, and test of evaluation studies. It was developed by Loral Advanced Distributed Systems under sponsorship by the Defense Advanced Research Projects Agency (DARPA) and the Simulation, Training and Instrumentation Command (STRICOM). It provides simulated forces and

environmental effects on a virtual battlefield. It allows the user to create and control entities on a simulated battlefield and allows other users access to the behaviors. Various entities (configured at the vehicle, section, flight, squad, platoon, company, and battalion echelons) simulate tactics and behavioral characteristics. These entities, ground vehicles, aircraft, dismounted infantry (DI), missiles, and dynamic structures can interact with each other and with manned individual entity simulators. They possess extensive capabilities. They can move, shoot, communicate, react, and be tasked to execute missions without human intervention. Unfortunately, ModSAF behaviors are generic in nature. Therefore, both friendly and enemy units participating in the simulation share the same behavior.

ModSAF software is written in C and can be run on both Unix and NT workstations. It is comprised of a set of software modules and applications used to construct Advanced Distributed Simulation (ADS) and Computer Generated Forces (CGF) applications. It has an open, modular architecture that segregates its functionality into libraries with strictly defined interfaces. These libraries are accessible by other users and can be used to define new entities and behaviors or build new applications to control ModSAF entities.

The fundamental element of ModSAF behavior is a task. A task is a single behavior performed by a unit or individual on the battlefield. There are five different types of tasks in ModSAF: unit, individual, reactive, enabling, and arbitration. Unit and individual tasks are behavior tasks that perform activities that real units or individuals would perform on the battlefield. An example of a unit task is 'Conduct a Platoon Roadmarch'. An example of an individual task is 'Avoid Collisions'. Reactive tasks are behavioral tasks used to trigger reactions to battlefield activities or events that might be

encountered by an individual or unit for example 'Conduct Hasty Attack'. Enabling tasks are behavioral tasks that happen because of mission contingencies and can trigger other missions such as 'Crossing a Phase Line'. A phase line is a control measure used to control military operations. Arbitration tasks are tasks that are used to help prioritize competing behavioral tasks during a mission. For example, if a tank has been tasked to conduct a move from Point A to Point B and detect enemy vehicles, then an arbitration task will decide which competing task takes priority given the current battlefield environment.

Tasks are grouped together into task frames. A task frame is a group of one or more tasks that are assembled by an operator before simulation run time and are executed simultaneously during a single phase of a mission. Task frames are placed on a task frame stack at run-time. A task frame stack is a run-time data structure that assigns task frames to specific entities or units for a particular phase of an operation. The task frame that is place on the top of the stack is the set of tasks that entities are currently executing. As the entities progress during the execution of their mission, task frames are updated. A task manager controls the execution of tasks during the execution of a mission. It manages the task frame stack updating task frames when necessary and handles the transitions between phases of the mission.

Tasks are implemented within ModSAF as Asynchronous Augmented Finite State Machines (AAFSM). A Finite State Machine (FSM) defines a set of states which represent the low level actions that comprise a task and a set of transfer functions which can cause a transition to new states when certain inputs to the FSM have been satisfied. In ModSAF, FSMs are asynchronous because they can generate outputs in response to events in the synthetic environment, not based on a time function. FSMs

are augmented because they can cause a change in an entity's state and change the memory of the program. FSM will be discussed in detail later in chapters 2 and 3. (Calder, Smith, et al., 1993)

1.4 ModSAF Software System Architecture

ModSAF has three software components the SAF station, which allows an operator to create, load, and run scenarios that simulate a battlefield situation; the SAF Logger, which records and plays back exercise scenarios conducted on the simulated battlefield; and the SAFSim, which simulates entities, units, and environmental processes. These components are instantiated into executable application programs. ModSAF can be distributed over a Local Area Network (LAN) as is illustrated in Figure 1.5 with several computers participating or run on a single computer. When ModSAF is distributed over a network, physical battlefield states and events are communicated via the DIS protocol and information about missions and mission states communicated over the Persistent Object (PO) Protocol. The PO Protocol is used for all communications between all ModSAF systems. (Ceranowicz, 1994)

The SAF station allows an operator to monitor and control ModSAF forces and to setup a ModSAF exercise. It provides the Graphical User Interface (GUI) devices that allow the operator to monitor the tactical situation and generate missions for the entities. The operator monitors the status of the forces that he commands by reading a message log that contains unit status reports. He is able to generate missions for his forces by linking together a sequence of tasks using an editor called a task execution matrix. These missions are then issued to the forces for execution and can be interrupted or modified if necessary. The SAF station does no simulation, but requests

that the entities are simulated and that assigned missions are executed. The SAFSim is the component that accepts these requests and executes them.

The SAFSim is the component that simulates all the vehicles and units generated by ModSAF. The definition for each entity is done at run time by reading

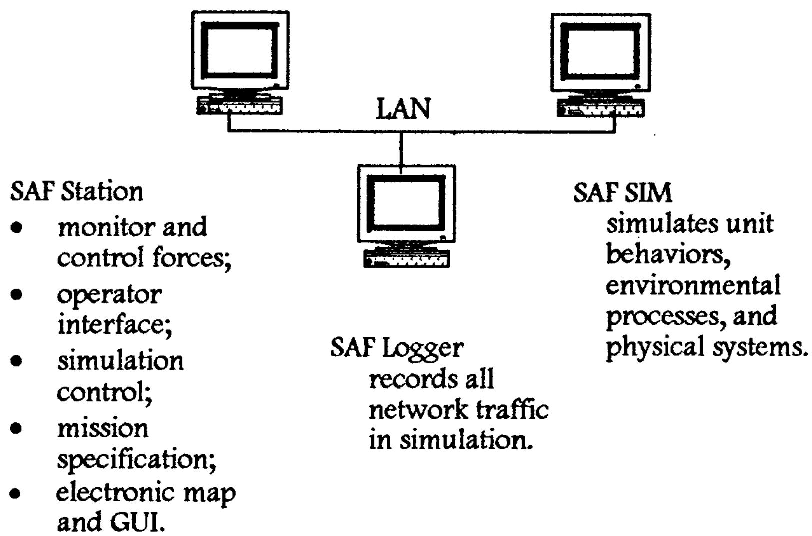

Figure 1.5 ModSAF Software System Architecture

parameter files. These files determine what the parameters will be for specific entity model and what software module will be used to simulate the entity. The SAFSim simulates both behavior and physical systems. These systems interact through standardized interface devices. (Ceranowicz, 1994)

The SAF Logger records all events in a ModSAF simulation. It captures the physical state of each entity in the simulation and the state of their mission by recording network traffic. It captures physical battlefield states via the Distributed Interactive Simulation (DIS) protocol and information about missions via the Persistent Object (PO) protocol. This allows the operator or analyst to playback an entire exercise or just

certain portions that might need further analysis. The SAF Logger also allows an operator to reinitialize a new scenario from any point in a previously recorded exercise, letting the forces re-execute the remainder of the mission. (Ceranowicz, 1994)

1.41 ModSAF Terrain

ModSAF uses both a Compact Terrain Database (CTDB) and a quadtree terrain database to represent battlefield terrain. The CTDB format generates an effective representation of the synthetic terrain in terms of soil type, feature data, and elevation supplemented with specific terrain called micro-terrain. Micro-terrain is a more detailed representation of a specific piece of terrain that the user wants to model. The quadtree terrain database is used to represent terrain features as objects in a spatially organized manner to allow a more effective structure for intelligent reasoning. Features in this database can include roads, rivers, and man-made objects such as bridges. (Petty, 1995) ModSAF has incorporated weather effects into the simulation database to create more realistic combat situations.

1.5 ModSAF Operator Control

In a paper titled "Operator Control of Behavior in ModSAF", Ceranowicz, Coffin, et al., describe three methods that an operator can use to control behavior in ModSAF: preplanned (programmed), automated reaction, and immediate. Currently, all three methods of control are simultaneously used in ModSAF based training simulations. In preplanned control, groups of tasks are connected to form a mission plan. This mission plan is assigned and executed by an entity. In automated control the control logic embedded in the SAF causes entities to react to activities or situations

happening on the synthetic battlefield. The operator for specific missions can adjust the parameters that control this type of behavior. In immediate control an operator gives a command that is immediately executed by the entity. It is used to make quick adjustments to the current tasks that the entities are performing as a result of changes on the virtual battlefield. A tank platoon tactical scenario, Figure 1-6, is developed to further illustrate these control methods.

1.51 Platoon Counter-Reconnaissance Mission Scenario

According to Army Field Manual 17-98, a counter-reconnaissance mission is an operation directed at preventing the visual observation or infiltration of friendly forces by enemy recon elements. This equates to a specific unit being assigned responsibility for fulfilling this mission several kilometers in front of the friendly force main defensive positions. At the battalion level a reinforced tank or mechanized company working with the battalion's scout platoon is assigned this mission. As such a tank platoon that is part of this company/team would occupy a platoon defensive position in its assigned area of responsibility and be prepared to transition to an offensive type operation when enemy vehicles are found. Figure 1.6 represents the area of responsibility within a counter-recon zone that a tank platoon as part of a company/team organization would be assigned. This zone is usually about 4 Kilometers (KM) wide by about 5 KM deep. In this scenario, the tank platoon leader has already conducted the necessary planning for his mission. He has conducted communications checks with his higher commander (company commander), the friendly scout section in his sector (represented by the blue triangle), and his platoon. He has rehearsed the probable enemy routes into his sector (routes 1,2, &3) and is executing a defensive mission. In this scenario, an enemy recon

vehicle has entered the tank platoon leader's sector in an unexpected and unplanned area. The tank platoon, consisting of four tanks, must be prepared to transition from a defensive to an offensive operation to find and destroy the enemy recon vehicle when notified of its presence.

1.52 Pre-planned Behavior

Preplanned missions are similar in nature to the mission plans or OPORDs created by Army staffs. They are divided into a sequence of phases that designate either

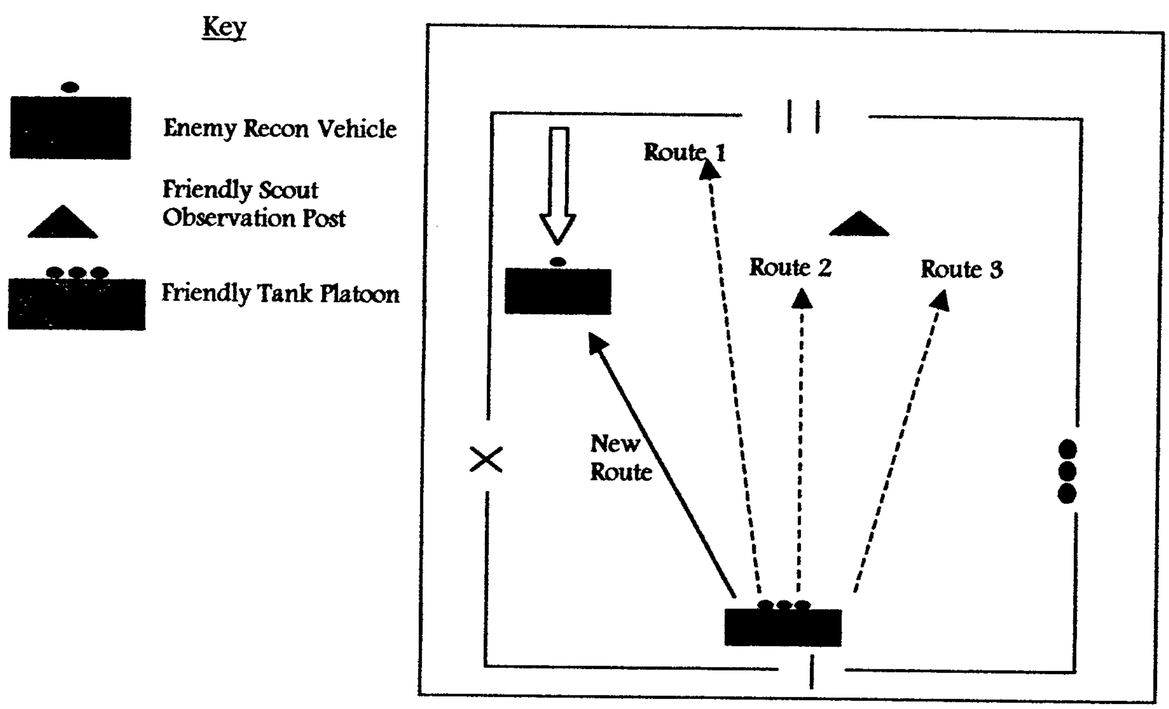

Figure 1.6 Platoon Counter-Reconnaissance Tactical Scenario

an individual entity or a unit specific responsibility for performing a task or a sequence of tasks. These missions usually occur before simulation run-time. An example of a

preplanned mission for the tank platoon in Figure 1-6, would be tasking it the on order mission to conduct a movement to contact (military offensive operation). The platoon would move from its counter-recon position along routes 1-3 to meet and destroy any enemy recon vehicles that have been sighted by the scout section in sector. This means that when certain parameters or criteria have been met, then the tank platoon would move along route 1, 2 or 3. For additional planning and control, the operator can phase the military operation. Time, distance, terrain, a change in task organization or a specified end state can characterize a phase. An execution matrix with units along the y-axis and phase along the x-axis assists the operator in monitoring the operation. Editors associated with each task allow the operator to examine and modify individual task parameters.

1.53 Automated Reactions

In an automated reaction, the control logic embedded in the SAF causes the entities to react to activities or situations. The operator can modify the parameters associated with each reaction based upon new TTPs or other guidance from the force that is being trained. Each reaction is embedded in the ModSAF architecture by a task representing a reactive trigger (i.e. actions on contact) and task frames representing a specified reaction (i.e. contact drill). ModSAF has the capability of handling multiple reactions simultaneously. A task hierarchy exists to trigger higher priority reactions when applicable. When an automated reaction is invoked, the preplanned mission is suspended. This state exists until the conditions that triggered the reaction cease to exist; at which point the preplanned mission becomes active again. An example of an automated reaction in the tank platoon scenario would be the tank platoon

automatically engaging the enemy recon vehicle with direct fire when it is in sensory range.

1.54 Immediate Action

An operator can modify preplanned missions during execution by direct manipulation of task parameters. Direct manipulation is the ability to take an object visible on the battlefield and perform an action on it that alters its behavior. This action can result from the operator gaining new information (similar to an Army FRAGO) during the course of the simulation, an unexpected contingency that arises, or just a personal desire. In Figure 1.6 when the human operator is made aware that an enemy recon vehicle is in an unexpected area of the recon-zone either because of either a radio transmission from the scout OP or a tank's sensors picking up the enemy vehicle, immediate control by the human operator from his SAF station would be necessary to get the tank platoon to act on the information and destroy the vehicle. By overriding the task parameters in the persistent object database for this new task, the operator can modify the task parameters for the just this mission or on a permanent basis for all future uses of the model. The persistent object database is an object-oriented database that contains command, environmental, and behavioral information. Once these parameters have been modified, the task manager will notice the task's new parameters when asked to execute it and will execute it accordingly.

1.6 Operator Interface

An operator interfaces with the ModSAF system through a standard computer keyboard or mouse. An electronic map and situation display illustrated in Figure 1.7

allows the operator to view the terrain and monitor the actions of forces on a synthetic battlefield. A graphical user interface (GUI) gives the operator access to: terrain analysis tools, which allow him to evaluate visibility and specific terrain cross-sections on a synthetic battlefield; drawing tools, which allow the operator to draw control measures on the map; and editors, which allow him to create, monitor, and control both individual and unit entities.

1.7 ModSAF Behavioral Representation Limitations

As has been demonstrated, there is no organic behavioral model in ModSAF that conducts self-modification of tasks based purely on observation and monitoring of the battlefield. For example, in Figure 1.3 when an enemy recon vehicle showed up in an unexpected area of the counter-recon zone and the tank platoon was made aware of it, human intervention was necessary to get the tank platoon to transition from a defensive to offensive mission posture. This method of control does not represent how a military leader would monitor operations, replan tasks, and control the execution of these tasks in a live tactical situation as discussed in paragraph 1.21.

Leaders can not and should not control every activity or event. Why not? The behavior of subordinate leaders is influenced through the issuance of orders and signals. It is the leader's responsibility to ensure that his subordinates understand his intent for mission execution prior to conducting the operation. Subordinates must have the ability and flexibility to make decisions on their own and replan their own operations accordingly based on monitoring their environment and the very real possibility that communications will be interrupted. An ability, to self-modify or

autonomously replan behavior in the context of the overall mission forms the basis for a successful military operation and is necessary to be replicated in simulation.

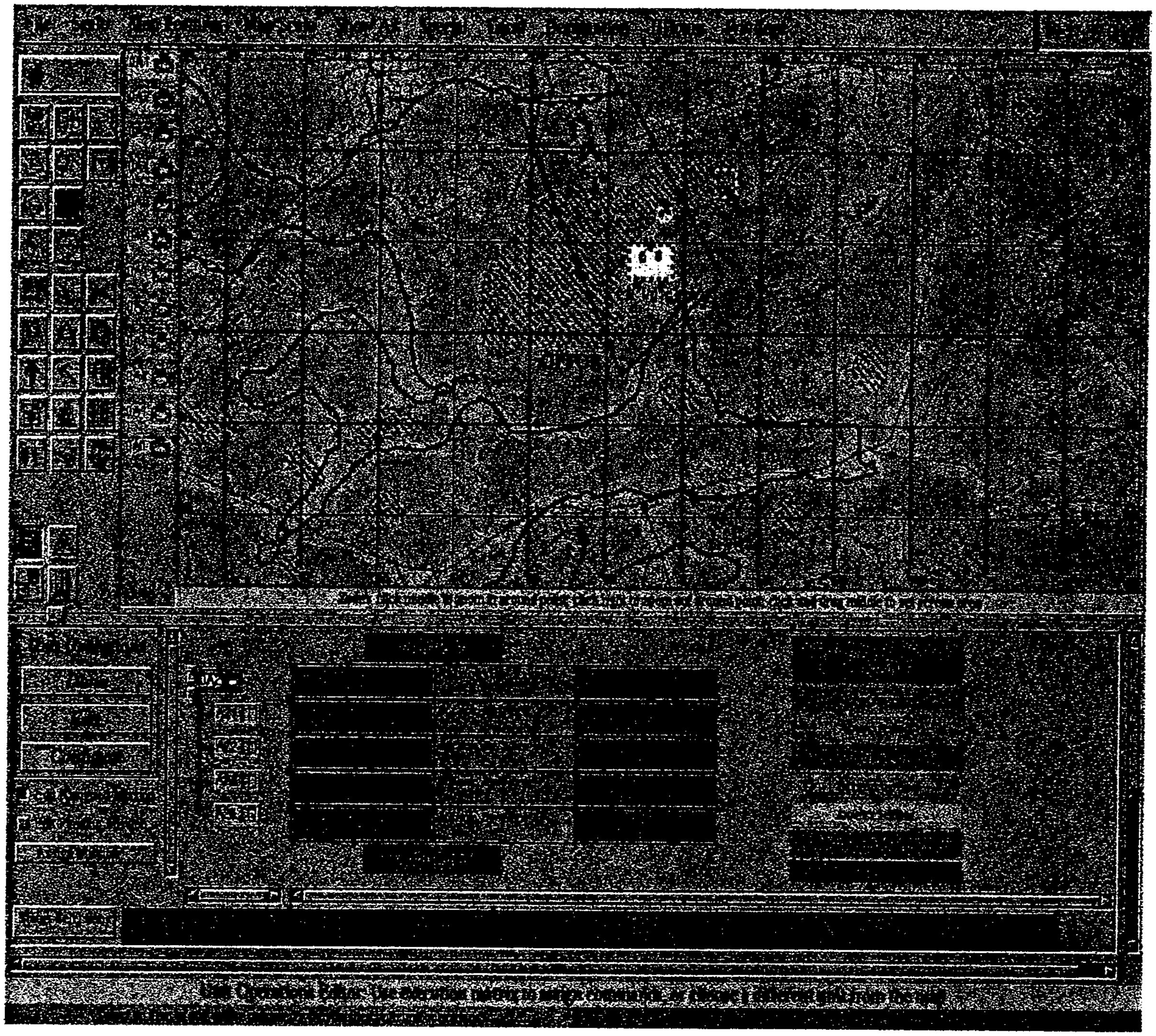

Figure 1.7 Sample ModSAF Tactical Scenario Screenshot

Currently, a company commander taking part in a simulated combat operation does not have to contend with any of the friction found in many real world operations as described in paragraph 1.11. This is because of a limitation of the training system.

If the company commander tells one of the tank platoons under his command to move to Point A, then that unit will move to Point A. This is because the company commander from his computer workstation inputs the instructions for that platoon not one of his subordinate platoon leaders that is charge of the platoon. This process is described in paragraph 1.54 (Immediate Action). If the company commanders are micromanaging the actions of their subordinates, then by default the system is allowing them to provide perfect information and intelligence to the battalion commander and his staff on the events unfolding in their particular areas of responsibility. This allows a battalion commander and his staff to make more informed decisions based on wholly accurate information; a capability that does not exist in live tactical situations. Thus, in reality the battalion commander and his staff are not being trained under realistic conditions because they know that the information that they are getting from subordinates is wholly accurate. Hence, the simulation is not fully representative of actual combat, but has lifted the friction and fog of war.

1.8 General Research Question

Because of the shortcomings in ModSAF's behavioral representation of human decision-making discussed above, I will examine several approaches and methods to answer the following research questions:

- Can behaviors of lower echelon units be implemented in a replanning behavioral model in ModSAF that more accurately depicts the flow of action and allows for self-modification of tasks based on observation and monitoring of the environmental situation?

- What is the most efficient and effective method of modifying the ModSAF behavioral model to gain this capability in terms of accuracy of situational representation?

2.2 Artificial Intelligence

AI is the branch of science concerned with the simulation of human intelligence processes by computer systems. These computer systems attempt to replicate the thinking and acting processes of humans in a rational manner. AI's focus is primarily on symbolic, non-algorithmic methods for problem solving. AI has primarily three objectives:

- make machines smarter;
- make machines more useful;
- and, better understand what intelligence is.

Some examples of what is considered intelligent behavior are:

- an ability to learn or understand from experience;
- capability of responding quickly and successfully to new situations;
- using reasoning in solving problems and directing conduct effectively;
- thinking and reasoning;
- applying knowledge to mainuplate the environment;
- and, understanding and inferring in ordinary, rational ways.

A critical component of any AI system is a knowledge base. A knowledge base is a collection of knowledge (facts, concepts, and the relationships) about specific topics that are organized together. A search or inference mechanism is used to search the knowledge base and attempt to find specified conditions or patterns that match predetermined criteria set up to solve a problem or make decisions. (Turban and Aronson, 1998)

2.21 Machine Learning

Machine learning is the branch of AI that studies the automated acquisition of domain-specific knowledge. The goal of these systems is to improve their performance

as the result of experience. Studies in this field include problem classification and decomposition, principals of intelligence, reasoning, and natural language processing. Machine learning is a framework for doing AI research and development. There are five main areas of machine learning: analytic learning methods; neural network (connectionist) learning methods; genetic algorithms and classifier systems; empirical methods for inducing rules and decision trees; and case-based approaches to learning. Neural networks and cased-based reasoning are the areas that this research focuses.

2.21.1 Neural Networks

Neural networks are a branch of machine learning that simulate human intelligence by reproducing the types of physical connections and function of the human brain. A neural network is configured for specific applications, such as data classification or pattern recognition. They can classify, categorize, optimize, and control behavior and are capable of adapting to changes in their environment. They learn through a learning process called training. Neural networks are used to solve problems that are too complex for conventional technologies such as when a problem does not have an algorithmic solution or for which an algorithmic solution is too complex to be defined. Neural networks can differ by the manner that their neurons are connected; the kinds of computations they perform; the manner in which they transmit patterns of activity throughout the network; and the manner in which they learn. Neural networks are best suited for problems that people are good at solving, but for which computers might not. (Turban and Aronson, 1998)

Unfortunately, neural networks have some detractors that make them difficult to implement into CGF simulations. They can not transfer their knowledge. This makes

it difficult to understand exactly how they generalized their knowledge and reached a conclusion. They can not use knowledge engineering acquired for other systems such as expert systems, which makes leveraging previous investments for these systems impossible. They operate on numerical data, which means that any symbolic information they receive must be translated. Finally, because neural networks must be trained, there is the question about what to train on and how much training is sufficient. (Command Decision Modeling Technology Assessment, July 1996)

2.21.2 Cased-Based Reasoning

The basis for case-based reasoning is to use a knowledge base of previous experiences (cases) to solve problems. Once this new problem is solved, it is then added to the knowledge base where it can be retrieved later to assist in solving any new problems with similar context. If the case is retrieved, it will be updated with knowledge on whether it successfully assisted in solving the new problem. Case-based reasoning uses analogy to these old cases to actually solve new problems and explains its rationale in terms of previous experience. Since human problem solving techniques use previous problem experiences to apply to solutions for new problems, cased-based reasoning is suitable for implementing into military CGF simulations. Unfortunately, the primary disadvantages of implementing case-based reasoning are the computational cost of obtaining solutions to problems (might have to search entire knowledge base to find similar case) and the cost associated with selecting, indexing, and maintaining a robust knowledge base. One of the more prevalent applications of case-based reasoning used in simulation is a computer agent. (Command Decision Modeling Technology Assessment, July 1996)

2.21.21 Computer Agents

Computer agents are computational entities that act on behalf of other entities. They have ability to anticipate, learn, and perceive situations about the environment that they reside. The majority of times these agents act on behalf of human sponsors. According to Dr. S. David Kwak in his paper titled "Synthetic Entities and Behavioral Representation", computer agents have the following characteristics:

- autonomy: agents operate without human intervention and have some control over their actions;
- social ability: agents can interact with other agents and humans;
- reactivity: agents perceive and react to the environment that they exist in;
- pro-activeness: the behavior of agents is goal directed and they can take the initiative in responding to their environment;
- and, mobility or the ability of the agent to move around a network.

Dr. Kwak further states that there are two types of agents: intelligent agents that can reason or plan and mobile agents that can transmit themselves across a computer network and then execute their tasks at a remote site. (Kwak, 1998) Much time and money has been invested into incorporating intelligent agents into military training simulations. Specifically, the military has examined ways to represent human tactical decision-making. These agents are called command agents.

2.21.22 Command Agents

There has been a considerable amount of exploratory research conducted on advanced, automated decision-making behavior in synthetic command agents. A command agent is a specific type of intelligent, computer agent. The Defense Advanced Research Projects Agency's (DARPA) Advanced Synthetic Command Forces (ASCF)

project is one such project that is exploring ways to imbed the functions of C2 in a synthetic command entity used in training simulations. A command agent is a software process that models the decision-making behavior performed by a trained individual or group in real planning or C2 situations without human intervention. Command behaviors include the ability to receive orders from a superior, plan missions for subordinates units, develop a situational awareness of the battlefield, monitor the execution of mission plans, and perform replanning when necessary. (Gratch, 1996) Command agents are intended to replace lower echelon tactical commanders, reducing the number of response cell operators required to administratively and tactically control the operations of smaller units in the virtual battlefield. Unfortunately, the focus of much of the research and developmental effort on these agents has been directed toward increasing their utility in modeling company command levels and above in training simulations.

2.22 Expert Systems

Expert systems are the branch of AI that applies human knowledge in a specific area to solve problems that normally would require human intelligence and intervention. Many of these systems are rule-based systems representing expertise knowledge as data or rules within the computer. These rules and data are called upon when needed to solve problems. The underlying premise for these systems is that problems in well-understood domains can be solved by transferring knowledge into rules created by Subject Matter Experts (SME) in that field. These rules are stored in a knowledge base and can be invoked by presenting a specific problem description that matches a rule in the system. Most expert systems are developed via specialized

software tools called shells. These shells come equipped with an inference mechanism and require knowledge of human expert behavior to be entered into the system via a specified format. System specific tools are used to write hypertext, construct user interfaces, manipulate lists and objects, and for interfacing with external programs and databases. According to Turban and Aronson, the purpose of an expert system is not to replace human experts, but to make their knowledge more available. (Turban and Aronson, 1998)

2.22.1 Finite State Machines

Finite state machines are a subclass of expert systems designed to conduct pattern recognition. They are formal process control mechanisms (rule-based) that are suitable for use in describing systems that are in one of a finite set of possible states and where a state transition occurs because of some event happening. A state is a condition or situation during the life of an object during which time it satisfies some condition, performs some activity, or waits for some event to occur. A state machine consists of a set of input and output events, a set of states, a function that maps states and input to output, a function that maps states and inputs to states (this is called a state transition function) and a specification that defines the initial state. In finite state machines, when an event occurs, the object responds by changing its state to reflect the new history of the object. The new state depends on the event that occurred, as well as on the previous state. This transfer from one state to another is called a state-transition. The event that causes a state transition is called a triggering event or, simply, a trigger. When a transition is triggered by an event, the object may perform some action that can generate new events. (Booch, et al., 1999)

2.3 Incorporating Autonomous Replanning into ModSAF

Considerable research has been conducted on how the capabilities of ModSAF entities can be enhanced to better simulate the conduct of realistic combat operations. Two of the more recent methods used to specifically enhance the autonomy and replanning capability in ModSAF entities are integrating command agents into the simulation and the implementation of specific behaviors as FSMs inside ModSAF tasks. Unfortunately, neither method provides an autonomous replanning capability in ModSAF at the platoon level that can functionally respond to unexpected events that take place in a simulation training exercise and does not require the intervention of a human operator. Therefore, this project will focus on the development of a behavioral model that will give a ModSAF entity such as a tank or tank platoon a replanning capability.

2.4 Recommended Behavioral Model

According to Dr. Kwak, FSMs are limited because they only represent a specific behavioral space with a predefined number of states. What this research is designed to determine is if a behavioral FSM is suitable for allowing ModSAF entities to modify their behavior in response to observation of the battlefield environment. It is believed that a specific enough problem space can be defined (i.e. a single platoon task) containing only a predefined number of states that makes an FSM suitable to answer the specific research question found in the next section.

Sumeet Rajput and Clark Karr from the Institute for Simulation and Training (IST) were able to develop a cooperative behavior mechanism in ModSAF using a FSM. This capability uses a Decentralized Control Architecture (DCA) that allows entities to

cooperate with each other directly with no supervisory control from an operator. The entity's cooperative behavior is implemented through FSMs and is described in data files. These ModSAF entities communicate with each other through the transmission of external events and communicate with each other through sending internal messages. In their model, a FSM engine written into ModSAF will read the description of the desired behavior and once predefined states have been met, executes the defined behavior.

Rajput and Karr's implemented the military task 'Bounding Overwatch' in a formal FSM in ModSAF Version 1.51 and tested it in a ModSAF scenario. Bounding overwatch is a tactical movement technique that is used by the United States Army in combat when enemy contact is expected. They had a mechanized platoon of four vehicles conduct the specified task and analyzed the results. The ModSAF entities performed the requisite behavior and demonstrated cooperation as predicted. (Rajput and Karr, 1996) Thus, a FSM can be used to implement a specific behavior successfully and is a viable candidate for the purposes of this research.

2.5 Specific Research Question

Given that the Army is relying more and more on computer simulations to train its personnel, the simulations that are used must accurately portray the behaviors of the forces that they represent. ModSAF is limited in its ability to represent an autonomous replanning capability in its synthetic forces. ModSAF is capable of executing the tasks 'Defend a Battle Position' and 'Attack by Fire' along a preplanned route once certain criteria has been met (SAIC 1999). Unfortunately, ModSAF entities can not autonomously plan new routes and execute new attacks based on an observation of the

synthetic battlefield because such an organic behavioral model does not exist. A higher level operator, thus creating unrealistic representation and outputs from the model, must input this behavior. ModSAF can transition between tasks or behaviors automatically (one task completed and next one is executed), triggered by a control measure on the synthetic battlefield, or through operator intervention. In order to get a ModSAF entity to act on information it has gained from either its own sensory capability or from a message transmitted to it by another entity requires human intervention (transition reason 3). An operator sitting at a computer workstation is necessary to first make the behavioral decision for the subordinate computer generated entity and then input the decision into the task matrix. This does not represent how military operations are conducted in a live tactical situation and should not remain the status quo.

Therefore, can a behavioral FSM be created in ModSAF that will allow a friendly tank platoon, employed in a counter-reconnaissance mission, to autonomously replan its behavior (transition from a defensive to offensive operation) based on observation of its synthetic battlespace; thus better representing human behavior and military combat operations?

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This research has identified different AI techniques for representing human behaviors in computer generated forces that are used in simulation. Now this research effort will address how to extend the application of these techniques into the problem domain (ModSAF) to better replicate how military leaders react in actual tactical situations. The research approach will be a case based study of two computer generated force technologies used by the United States Army. The purpose for these case studies is to determine if either technology possesses a behavior or capability that allows an entity to autonomously replan its behavior based on observation of its synthetic battlespace and can it be transferred into ModSAF. The two cases that will be examined for technology transfer are CCTT SAF and DARPA's CFOR command agents. Both technologies were discussed briefly in Chapter 2.

This research approach will follow the methodology described in Robert K. Yin's book *Case Study Research: Design and Methods; Second Edition.* It will be supplemented by interviewing Subject Matter Experts (SME), one an expert on ModSAF and the second an expert in Army tactics, techniques, and procedures employed at the platoon level. Existing Army doctrine provides the foundation for all of the military tactical operations described in this research.

3.2 Case Study Approach

This case study research effort consists of three phases. Figure 3.1 illustrates each phase and the associated critical activities that comprise it. Phase 1 is the 'Problem Definition and Case Study Design' phase. This phase defines the problem space, develops a theory on how to resolve the problem, selects specific cases to examine to

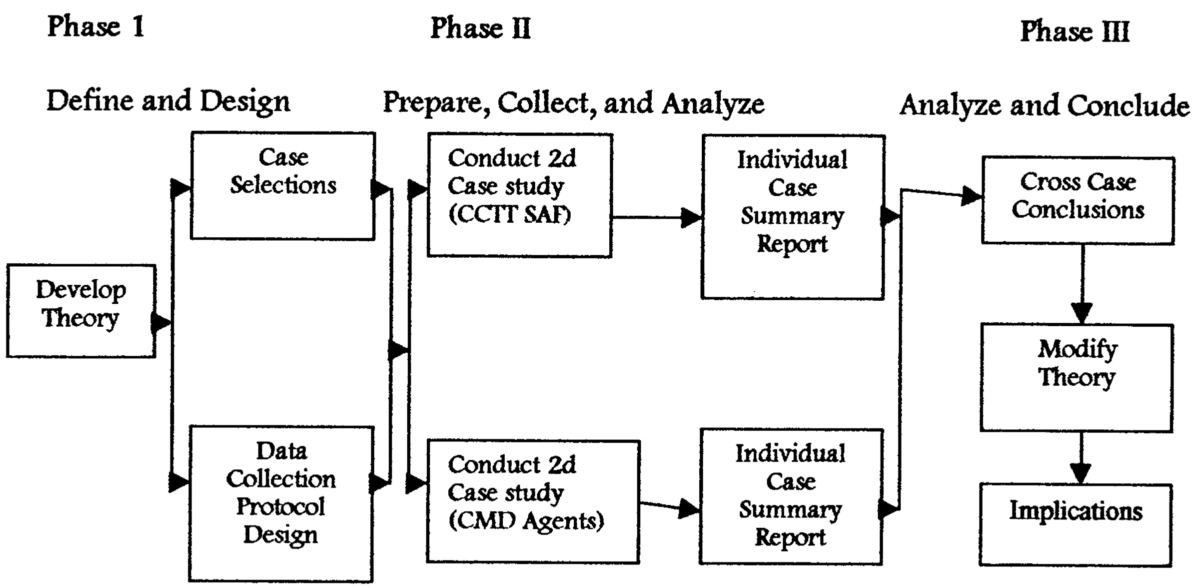

Figure 3.1 Case Study Research Approach Critical Activity Flow Diagram
(Taken and Adapted from Robert K. Yin's Case Study Research: Design and Methods; Second Edition, 1994)

determine if a case study can assist in problem-solving, and establishes the data collection protocol for the case study. Phase II is the 'Preparation, Collection, and Analysis' phase. This phase involves collecting and analyzing data from each case and concludes with a written summary report. Phase III is the 'Analysis and Conclusion' phase. This phase involves further analysis of the results of Phase II. It attempts to

draw conclusions about the practical implications for integrating these results into a behavioral model that can be implemented in ModSAF. Additionally, it validates or modifies the theory proposed in chapter 2.6 (Specific Research Question) and then proposes any follow-on research to implement the theory.

3.3 Phase I: Problem Definition and Case Study Design Phase

The first step in this phase is to define the problem space. This is accomplished by uncovering the cause of the problem, its component parts, and its effects. The behaviorial limitations for ModSAF based simulation training exercises were extensively developed and discussed in chapter 1 of this paper. There is not an organic behavioral model in ModSAF that conducts self-modification or replanning of tasks based purely on observation of the synthetic battlefield similar to the way that a military leader would under live tactical circumstances. Therefore, company commanders taking part in simulation based training exercises are forced to micromanage the actions of their subordinates through physically feeding commands into the simulation through their computer workstations. By default, this allows the company commanders to provide perfect information to their higher headquarters on the activities occurring in their area of responsibility giving a battalion commander and his staff a capability to make decisions based on wholly accurate information. This capability does not exist in most real tactical situations and must not be practiced in training.

The second step in this phase is to develop a theory on how to fix or mitigate the problem. This thesis proposes that a new behavioral model, specifically a FSM, be developed and implemented into ModSAF based simulation training exercises that will improve human behavior representation. Specifically, this behavioral model will allow

a ModSAF entity; employed in a counter-reconnaissance mission, to autonomously replan (transition from a defensive to offensive operation) its behavior based on observation of its synthetic battlespace. Hence, the FSM developed would not be generalizable beyond the problem domain; however, it could be generalizable to some extent within the application domain. The FSM technique itself can be applied to any application.

Prior to developing this behavioral model, the underlying tasks/events/transitions that are an integral part of the model must be realized. It is not until these items are found and validated can the research continue. This research will examine the tasks, conditions, and standards that are performed by a military unit during a counter-recon operation. It will focus at the tank platoon level and examine the causes for a tank platoon leader to change or replan his unit's task and then how the change is accomplished. An extensive literature search of current military doctrine supplemented with personal experience (based on over 10 years of armored warfare duty) and validation by a senior military SME on platoon level tactics will support this effort.

The literature search will examine several different military publications that contain information on counter-recon operations and military decision-making models. These publications will include Army Field Manuals (FM) and Army Mission Training Plans (MTP) which describe how to successfully conduct tactical operations. The SME will be interviewed to validate this information. Specifically, the SME will be interviewed to find out the following information:

- critical tasks or activities that make-up a successful counter-reconnaissance operation and how a tank platoon supports it.

- and, the critical role a tank platoon leader plays during a counter-recon operation and what might cause him to change his mission and how it is accomplished.

The third step in this phase is to select the cases for study. The two cases that will be studied are CCTT SAF which models tactical behaviors and DARPA's CFOR command agents which models human decision-making. These cases have been selected because they are currently used in Army training simulation and possess strong doctrinal foundations.

The last step in this phase is selection of the data collection protocol. This step contains the procedures and general rules that will be followed when studying the cases. The data collection protocol will consist of the following activities. First, a preliminary review of relevant literature on each case will take place. The purpose for this review is to gain familiarity with the instructional and administrative applications within each case, to a greater extent than was found in Chapter II. Journal articles, conference proceedings, and any other functional descriptions of the techniques used in a case will be examined. Then local site visits to the proponents for each case or their designated representative will be conducted. The purpose for each visit will be to observe a capability demonstration of the respective software; gain first hand information on how each case represents and implements human behavioral models into training simulations; and facilitate interviews with key software engineers to discuss computer algorithms and code if necessary.

3.4 Phase II: Preparation, Collection, and Analysis Phase

Phase II will be the actual case study phase. This phase will prepare, collect, and analyze data for each case study and gather all initial findings. This phase will be

guided by the protocol established in chapter 3.3 and will draw upon several different sources of evidence to ensure a thorough analysis. This will include the information that was discussed in the preceeding chapter (company literature, interviews with key organizational personnel knowledgeable on behavioral modelling techniques, and any direct observations).

3.5 Phase III: Analysis and Conclusion Phase

This phase builds upon the analysis that ended phase II and concludes with the implications that the case studies might hold on the proposed theory. The findings in this phase will constitute a significant portion of chapter IV in this thesis. This phase will compare the behaviors for each technology with those described as essential by Army doctrine and the Army SME. The purpose of this comparison is to determine whether or not the case can be useful for this research's cause. Specifically, pattern matching will be used during this comparative process to look for similarities. For example, the Army tactical SME says that these tasks are performed by a tank platoon during the conduct of a counter-recon operation and these are possible reasons that the platoon would shift from one task or military operation to another. The question then becomes: Does the case have a behavioral model or algorithm containing any of the tasks or tranisitions that would cause a tank platoon to autonomously replan its behavior? Can that capability or anything else of value be transferred into ModSAF?

Once the comparisons are made and analyzed, then the results will be consolidated and cross-case conclusions drawn. The results of each case study will address whether or not it has the requisite behavior or some similar capability and at what level can it be integrated into ModSAF to allow a tank platoon to replan tasks

based on observation of its synthetic battlespace. If the research question proposed in chapter 2.6 needs to be modified because there are no suitable techniques to extend human behavior representation to a more autonomous state in the problem domain (ModSAF), then this phase will implement the recommended modification.

Finally, if neither CCTT SAF nor DARPA's CFOR command agents have a behavioral model capable of replanning nor any other technique and/or technology suitable for transfer into ModSAF without excessive cost, then the next step is to develop a new behavioral FSM.

Table 3.1 summarizes the research data collection protocol for each case study and the techniques and technology that are tranferable into ModSAF. Column 1 lists

Case	Literature Review Completed	Demonstration Observed	SME Interview	Replanning Capability	Ease of Transfer	Other Techniques & Technology Transfer

Table 3.1 Proposed Case Study Summary Information

the case that was examined during the case study research (DARPA's command agents and CCTT SAF). Columns 2-4 lists the research goals set by the data collection protocol methodology developed in this chapter and whether the goal was reached. Columns 5-7 describes whether the case has a 'replanning' capability, if it does its ease of transfer,

and if there is any other techniques or technology that is suitable for transfer into a proposed ModSAF finite state machine.

CHAPTER 4

CASE STUDY FINDINGS

4.1 Introduction

This chapter outlines the results of the case study evaluation. It follows the data collection protocol established in Chapter III. First, the reasons surrounding how and why during a counter-recon operation a tank platoon leader would replan his unit's mission will be examined. Second, COL James Nunn, a SME on platoon level tactics, will validate these results. Third, an in-depth analysis for both DARPA's CFOR command agents and CCTT SAF will be conducted. Fourth, the results of these analyses will be consolidated complete with summary findings for each case. Then based on these summary findings, a comparative analysis will be made on how a military leader conducts replanning in the real world versus how these respective cases represent it in simulation. Finally, a determination will be made on how best to implement an autonomous replanning behavior into ModSAF. A comparison of these two case studies reveals that some techniques and/or technology should be transferred into any proposed behavioral model for ModSAF.

4.2 Counter-Reconnaissance Operations

According to Army Field Manual (FM) 71-123 (*Tactics and Techniques for*

Combined Arms Heavy Forces: Armored Brigade, Battalion Task Force and Company Team), counter-recon operations are any security operation taken to deny the enemy intelligence information concerning friendly units through the active defeat of that enemy's reconnaissance and surveillance efforts. A tank platoon in conjunction with other units would support this type operation by conducting a stationary screen forward of the main defensive area. During stationary screens, the tank platoon will occupy and defend a hasty platoon battle position (ARTEP task 17-3-2601) to acquire and destroy the enemy forward of this position. There is an understanding that the platoon may be forced to leave this position and conduct a hasty attack or attack by fire (ARTEP task 17-3-0219) to destroy the enemy if it is found in an unplanned area. Primarily, three reasons can cause a tank platoon leader to change his unit's mission. These reasons are:

- when ordered by a higher headquarters;
- receipt of a SPOT report that puts the enemy in an area that was not anticipated;
- and, after the completion of a reaction to an unexpected situations.

During a stationary screen, a tank platoon leader receives information on an enemy vehicle's location by three means. These are the receipt of a radio message transmitted to the platoon from either its higher headquarters or an adjacent unit, through an enemy contact report radio message transmitted by another tank in the platoon, or by detection with a sensor on his tank. Once the platoon leader receives this information, it becomes his responsibility to decide whether to act on it. Given the framework of his current mission, the platoon leader has three Courses of Action (COA) that he can choose from. The first COA is to maintain his status quo, continuing to defend from his current defensive position, hoping that the enemy recon vehicles will continue to advance towards his unit and then he can destroy them. The second COA is

to initiate an attack by fire. This attack would be executed along a preplanned route and should have been previously rehearsed. The third COA is to initiate an attack by fire against the enemy along a new route. This COA is the most difficult for the tank platoon leader to execute, but happens repeatedly in live tactical situations as the enemy situation always changes and the enemy infrequently goes where you would like. ModSAF entities are currently incapable of executing COA number three, and will be the focus of this research. Reactive behaviors such as reacting to enemy indirect fires, reacting to enemy air attack, or executing actions on contact will not be examined.

4.21 Change of Mission

In a case where the platoon leader is made aware that an enemy vehicle is about to bypass his platoon and penetrate the main defensive area, the platoon leader must act quickly or risk not accomplishing his mission. The platoon leader must:

- evaluate the report in order to determine if the information and its source is credible;
- assess the impact of the report on his unit and his current plan;
- and, decide how his plan must be modified.

For the purposes of this research, the platoon leader is forced to modify his plan. He must execute an 'Attack by Fire' (ARTEP task 17-3-2601) along an unplanned route. Therefore, according to Army Mission Training Plan (MTP) 17-237-10-MTP, the platoon leader must take the following steps. He must:

- analyze the terrain in relation to his and the enemy's locations;
- decide where the most advantageous location is to intercept and attack the enemy;

- identify a covered and concealed route to that location for his platoon to travel;
- coordinate with any other friendly units in his area of responsibility to let them know of his new COA;
- and, issue a FRAGO or new order to his platoon describing the new task, how it will be executed, and when it will be executed;

After all these steps have been accomplished, the platoon leader initiates movement and conducts an attack by fire.

4.22 Validation

Colonel (COL) James Nunn, a recognized SME on tank platoon tactics and currently assigned as the Army's Training and Doctrine (TRADOC) Systems Manager for the Abrams Tank, was interviewed during this research phase. His insights proved invaluable in capturing platoon level tactics. He was asked to validate the research methodology used to uncover the reasons behind why and how a tank platoon leader would replan or change his unit's mission. COL Nunn agreed that there are 11 steps that a platoon leader must take to transition his force from 'Conducting a Hasty Occupation of a Battle Position' to 'Performing an Attack by Fire'. These steps are listed in Table 4.1. He stated that of course given the dynamic nature of combat, these steps are rarely completed sequentially and sometimes if the situation dictates steps can be omitted. For example, if the platoon leader receives an enemy contact report and upon evaluation decides to act upon it, he could decide given pre-planned and rehearsed routes to launch straight from step 3 (Plan modification) to step 10 (Initiate movement).

COL Nunn then was asked to compare those reasons found during the literature review and reasons that he feels would cause a platoon leader to modify his unit's

mission. Based on comparison, he validated the following reasons to replan unit behavior:

1) Response to an order by a higher headquarters to change the unit's mission;
2) Receipt of an enemy contact report from another tank in his platoon or from another unit;
3) Upon the conclusion of a reaction to an unexpected event on the battlefield and the desire to get the original mission back on track.

COL Nunn went further to state that, in his expert opinion, any prudent tank platoon leader given the context of a similar operation (counter-recon) would replan his unit's mission for any one of these three reasons.

Sequence of Operations
• Defense of Hasty Battle Position (report/order received)
• Report/order evaluated and impact on mission assessed
• Plan Modified if necessary
• Terrain Analysis conducted
• Advantageous terrain to attack enemy is selected
• Cover and concealed route to move along is selected
• Coordination with units that might be affected by new plan is conducted
• FRAGO is issued to platoon
• Higher headquarters informed of intent
• Necessary movement initiated
• Platoon performs new task (Attack by Fire)

Table 4.1 Sequence of Operations for Mission Change in Counter-Recon Operation

In conclusion, COL Nunn felt that the research methodology employed in this thesis as it pertained to military tactics, techniques, and procedures was sound and that the results (criteria for replanning and steps used to replan) were accurate and doctrinally sound.

4.3 Command Agents

Command and control simulation training exercises require a large number of trained response cell operators and role players to control the operations of the units participating in the exercise. In 1995, the Defense Advanced Research Projects Agency (DARPA) initiated the Command Forces (CFOR) program to examine ways to reduce this requirement while still training high level commanders and their staffs. The intent for the CFOR program was to develop an automated, synthetic Command Entity (CE) or hereafter described as a Command Agent (CA), capable of representing the functionality of military commanders on a synthetic battlefield, thus allowing a smaller number of human operators to control a greater number of entities. A synthetic CA is one of three types of command entities discussed on page 57. These CA would be responsible for commanding computer-generated forces used in the simulation, be responsible for responding to changes on the synthetic battlefield without human intervention or interaction, and be responsible for communicating/interacting with live command entities in the simulation. (Foss and Robinson, 1999) This allows a CA the following operational capabilities:

- receive and analyze orders and reports from superior headquarters and subordinates;
- analyze terrain for planning tactical operations;
- plan and issue orders for its subordinate units (CGFs) to execute;
- command and control subordinate unit activities;
- monitor the synthetic battlefield to include how well a subordinate unit is executing its mission;
- and, perform replanning as a response to an unexpected event or report from a higher headquarters.

These operational capabilities make a CA very representative of a live human. (Calder and Chamberlain, 1998)

In October 1997, command entities from the U.S. Army, Navy, Air Force, and Marine Corps interacted with each other and with credible opposing force objects during a multi-echelon, joint DOD computer driven C2 simulation training exercise called Unified Endeavor 98-01. This exercise was ModSAF based and used automated command agents to represent entity-level forces for units from all branches of the services. The command and control for these agents was exercised by human commanders sitting at CFOR workstations. Overall, CA performance during the exercise was classified a success. Command agents were able to automate lower echelon command and control during this exercise. The Joint Task Force commander and his staff were trained without degradation at less cost in terms of the number of personnel required to administratively support the simulation. However, there were a number of technical and operational issues raised during the exercise.

In his paper titled, "Performance of the DARPA Command Forces Program in the STOW 97 ACTD", James Calpin of the Mitre Corporation reviewed the performance of command agents during the exercise described above. While he states that the CFOR program as a whole was an "unqualified technical and operational success", he still believes that the CFOR CE program could be improved. He gave three major examples where improvements would enhance functionality and ease-of-use of CFOR software. First, he feels that the current CCSIL message format is too constraining and complex. Operator are spending too much time inputting operations orders and other messages into the CCSIL format. Secondly, he thinks that there needs to be provisions in the architecture to allow for the transition of command to a subordinate when the vehicle

or entity representing the CA is destroyed. Currently, when the CA is destroyed, the entities subordinate to the CA continue executing their last mission. It takes a human operator to intervene and change the tasks matrix. Finally, he believes that if the CFOR CE technology is to be extended to other applications and programs, then the software needs better documentation with ease-of-use a major consideration. (Calpin, 1998)

4.31 CFOR Architecture

Before continuing, it is necessary to understand the architecture that allows the interaction between real humans and synthetic entities described above to occur. A command entity is defined as an entity capable of exercising C2 over another entity. It can be represented in three ways: a live human being working at a C2 workstation; a complex software application such as the automated command agent discussed above; or as a synthetic entity belonging to a traditional CGF application like the abstractions of leaders embedded in ModSAF. The software that is used to support CFOR is designed utilizing an object-oriented methodology. It is organized so that general knowledge is contained in generic base classes and domain specific knowledge is contained in classes. This facilitates maximum reuse of already developed software. The software is implemented in C++. (Calder and Chamberlain, 1998)

Figure 4.1 illustrates the architecture used for a simulation training exercise involving all three types of CE's. The left box represents a real human command entity, the middle box represents an automated command entity (CA), and the right box represents a traditional abstraction of a leader in a CGF application like ModSAF. A human computer operator is necessary to run both the CA and CGF application workstations. In this example, there is a real world message network for voice

communications between human operators manning all three CE workstations and a second Distributed Interactive Simulation (DIS) network or LAN that physically connects the command entities to each other. This DIS network simulates a second real world radio network that a unit participating in the exercise would have and allows simulation messages to be passed back and forth between CEs via signal Protocol Data Units (PDU). A special interface language is necessary to facilitate this communication. In this example, the Command and Control Simulation Interface Language (CCSIL) developed by the Mitre Corporation is being used. CCSIL is an embedded software

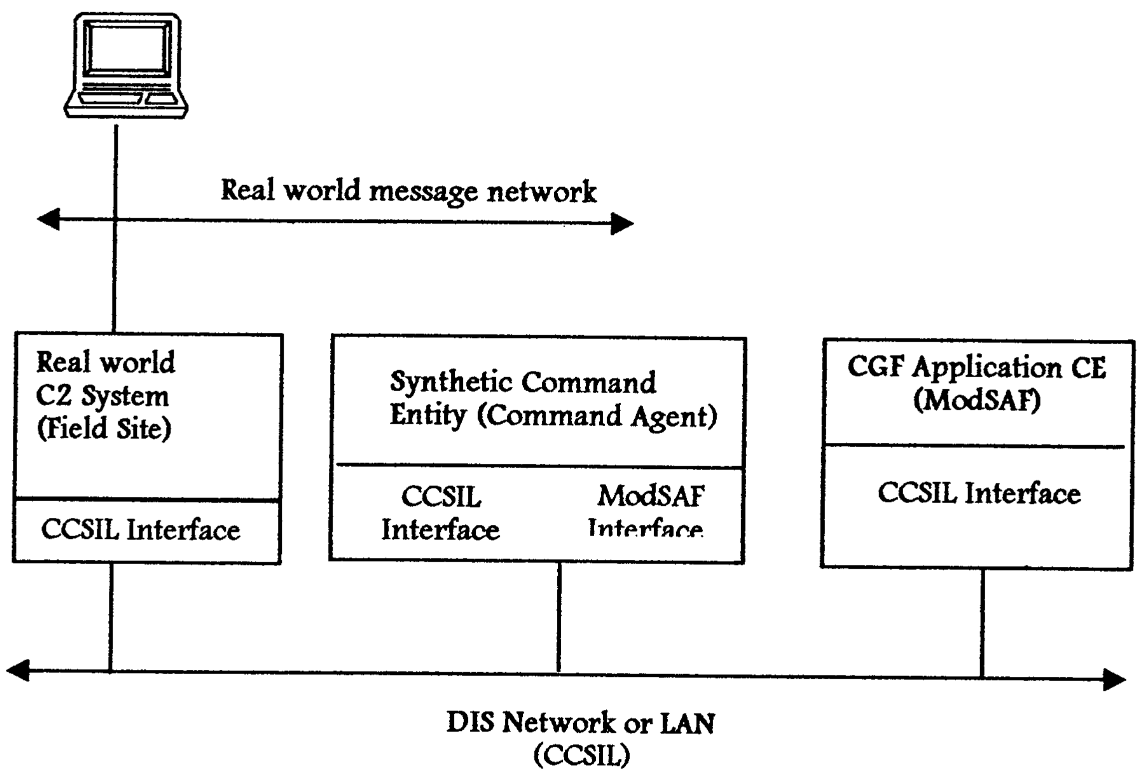

Figure 4.1 Architecture for a Training Simulation integrating Command Agents (Salisbury, Seidel, et al., 1995)

language that allows CE's participating in a simulation to communicate and work together in a single environment. It consists of an abstraction of real world messages that get passed between decision nodes during an exercise putting them into a common messaging format more suited for software-software interactions. These messages can include standard interactions such as operations orders, time-driven information such as status reports and situationally triggered exchanges such as enemy contact reports and fragmentary orders (FRAGOs). The baseline CGF application must be modified to accept and implement these CCSIL messages. In this example ModSAF has been modified. (Calpin, 1998)

4.32 Command Forces Infrastructure

Command agents are implemented into a simulation through a specialized framework especially developed for the CFOR program called the Technical Reference Model (TRM). The TRM, illustrated in Figure 4.2, provides a well-defined, common interface for all command decision activities within the synthetic command entity and allows it to interact via a DIS network with other CEs in the simulation. It promotes interoperability and C2 activity by providing a shared infrastructure, application interface, and common set of information and computing services. For instance, the TRM allows individual CE's to manage their individual weapon systems, communicate in the synthetic battlespace with other CEs, conduct basic terrain recognition and reasoning, and access common procedural and doctrinal information. The TRM is comprised of three layers. There is a CE Application layer, a CE Information Services and Utilities layer, and a CGF Application layer. (Calpin, 1998)

4.32.1 Command Entity Application Layer

The CE Application layer is where all command decision-making processes take place to include planning, coordinating, communicating, monitoring and executing tasks during a simulation. This is accomplished by encapsulating several functional

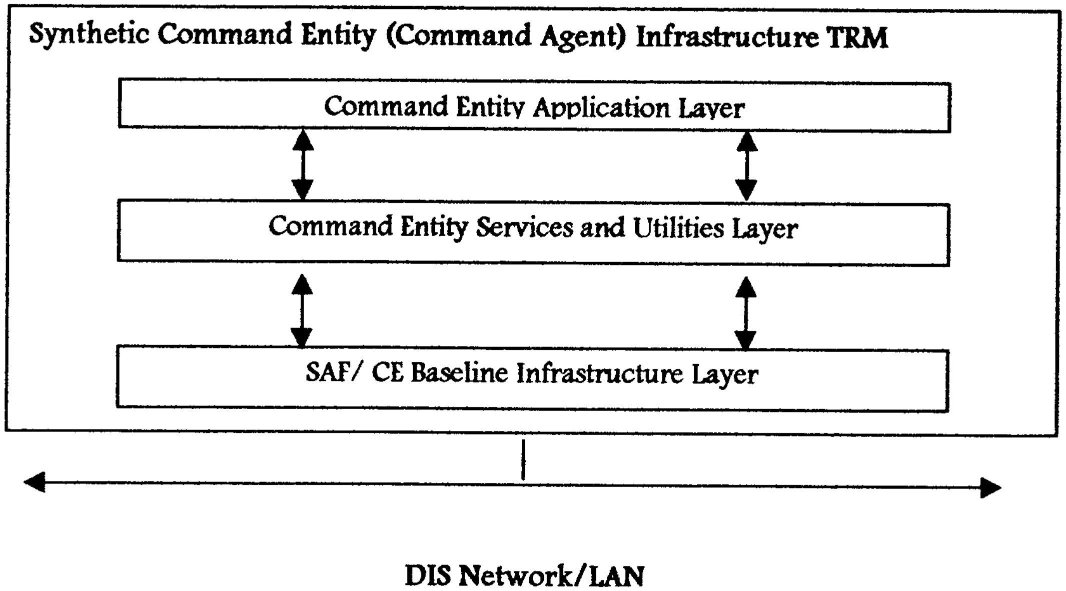

Figure 4.2 Top Level Synthetic Command Entity Infrastructure Diagram

subcomponents or modules into a commander object that resides within this layer. This synthetic command object or CA is illustrated in Figure 4.3. The interface between the subcomponents embedded in this layer and invoking properties of both the CE Utilities and Services layer and SAF/CE Baseline when necessary allows the CA to operate in a seemingly autonomous fashion. The subcomponents embedded in the CE Application layer are a communications module, an event processor, a situational awareness module, a tracker module, a plan module, a planner module, and a terrain analysis module.

The communications module provides interfaces for sending and receiving CCSIL messages, which allows the CA to communicate with other CE's during a simulation. The communications module interfaces with the situational awareness module, event module, plan module, and of course outside CEs. It provides information to the situational awareness module allowing it to maintain an accurate representation of the current state of the synthetic world. It provides critical

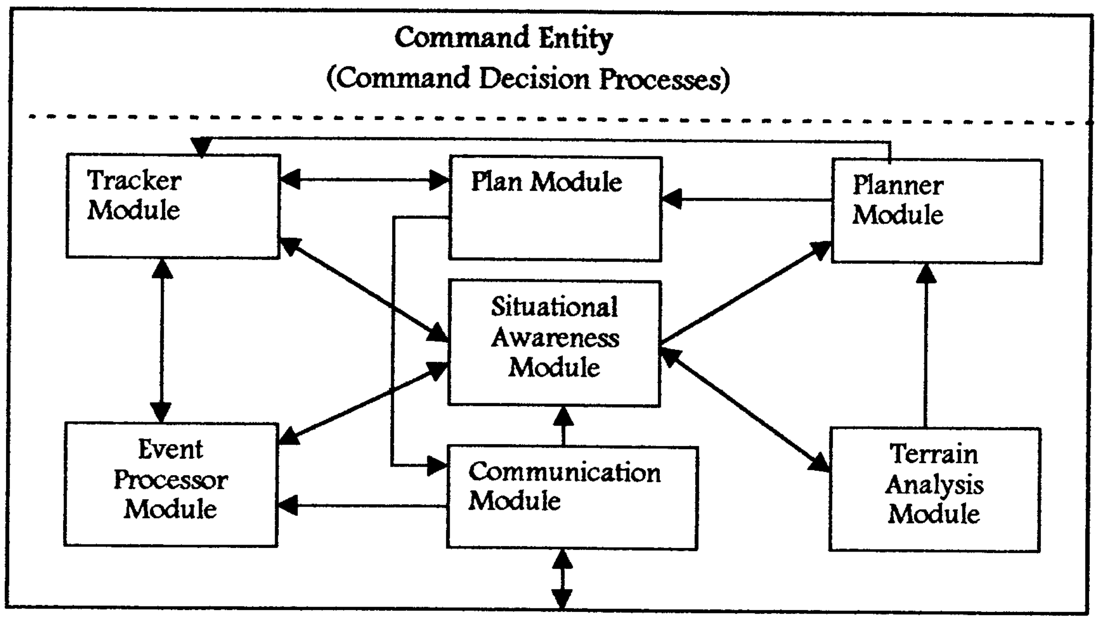

Figure 4.3 Command Entity Application Layer Diagram (Calder and Chamberlain, 1998)

information on what is taking place in the simulation to the event module. It provides the means by which messages or orders are sent from the plan module to other CEs.

The event processor monitors all events happening on the synthetic battlefield, informing the CA about events that might affect it. It receives information from the communication module and provides information to the tracker module when queried.

The situational awareness module is responsible for the representation of the state of the synthetic world. It receives information from multiple sources to accomplish this, including CCSIL orders and messages from higher level commanders, from subordinate units, and sensory data from queries via the platform behavior module located in the second layer of the TRM. If a CA wants the state of another CE involved in the simulation, then it accesses this module.

The tracker module monitors the CA's mission execution against the current plan. It accomplishes this by interfacing with both the plan and planner modules to see whether the CA has deviated from the original plan. The tracker module is also responsible for 'tracking' key events taking place on the synthetic battlefield and reporting them to the situational awareness module for possible future action.

The plan module provides a representation of the CA's current mission, developed by the planner module, so that it can be 'tracked' for verification. It is invoked when a new plan is received. It will then send the plan to the Tracker module for 'tracking' and to the communications module for dissemination to subordinate units.

The planner module is responsible for generating, evaluating, and selecting a course of action that satisfies the mission requirements specified by the CA's higher echelon headquarters. It is invoked when an order is received from a superior to execute a specific military operation or when the situation dictates. In either case, the planner module interfaces with the tracker, situational awareness, and terrain analysis modules to identify when these criteria for replanning have been met and a new plan is necessary and can invoke properties from both the CE Utilities and Services layer and SAF/CE Baseline. Specialized computer software embedded in the planner module

generates any new plans. This software employs an approach based upon constraint satisfaction to perform its functions and is discussed in greater depth in paragraph 4.32.4. (Calder and Chamberlain, 1998)

The terrain analysis module allows the CA to access terrain data when executing a mission or generating a new plan. It utilizes information from the environmental utilities library, located in the CE Information Services and Utilities layer of the TRM, to provide services for terrain analysis in preparation for mission planning (Planner module) or locating enemy positions (Situational Awareness module) during the context of an operation. (Calder and Chamberlain, 1998)

4.32.2 Information Services and Utilities Layer

The Information Services and Utilities layer provides the information needed to support the decision-making that takes place in the Application layer. It consists of four modules: the platform behavior module, the communications module, the command and control utilities module, and the environmental utility module (see Figure 4.4). Each platform is actuality a library containing information that a CA will invoke by a direct function call when necessary. The platform behaviors module provides a generic interface to a command entity's physical representation on the battlefield. It uses the basic behaviors and functions in the CGF application that is being used in the simulation like shoot, move, and sense (shown as subsets of the Platform Behavior Module in Figure 4.4). The communication platform module provides reliable CCSIL communications among command entities via the DIS network. The C2 utilities platform module through its subsets illustrated in Figure 4.4 provides CE's access to routine knowledge that is shared by every human commander such as tactics,

techniques, and procedures or information on various missions and supporting tasks. This knowledge does not depend on subjective judgments, but is objective information containing doctrinally acceptable decision options for conducting an operation. The C2 utilities platform additionally provides a CA access to static data about units involved in

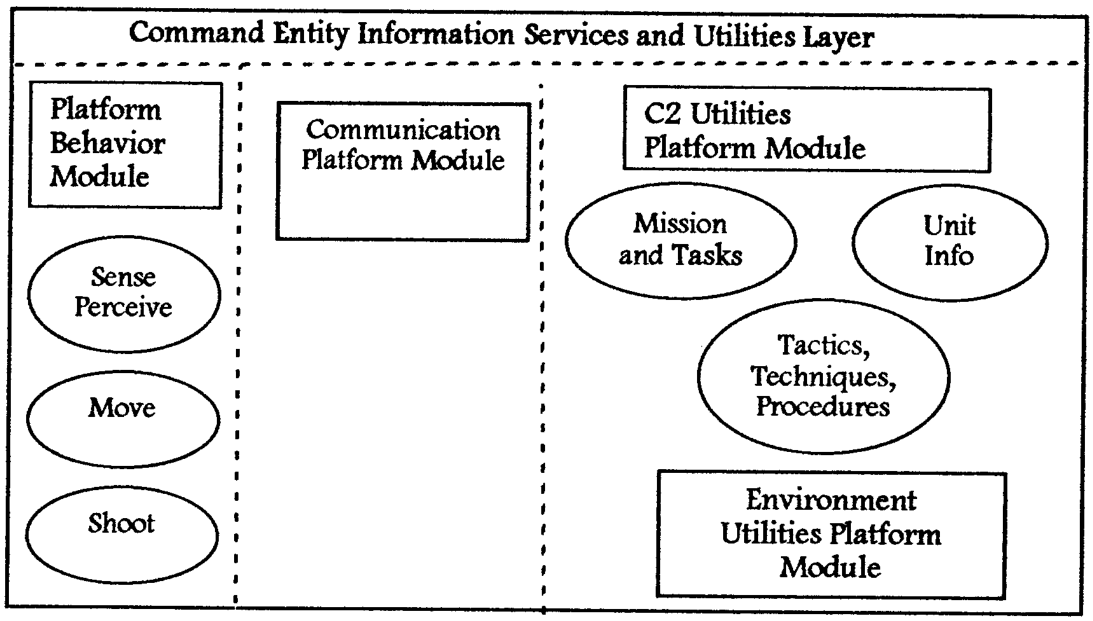

Figure 4.4 Command Entity Information Services and Utilities Layer Diagram

the simulation. The environmental utility platform provides access to terrain, ocean, and atmospheric data to support maneuver-oriented reasoning. (Salisbury, Seidel, et al., 1995)

4.32.3 CGF Baseline Infrastructure Layer

The CGF Baseline Infrastructure layer provides the basic platform representation and general DIS interface utilities accessed by a CA. The major components of this

layer are illustrated in Figure 4.5. The CGF application provides the baseline infrastructure for the simulation training exercise. The CCSIL network interface provides the CA access to the CGF infrastructure and allows it to communicate with

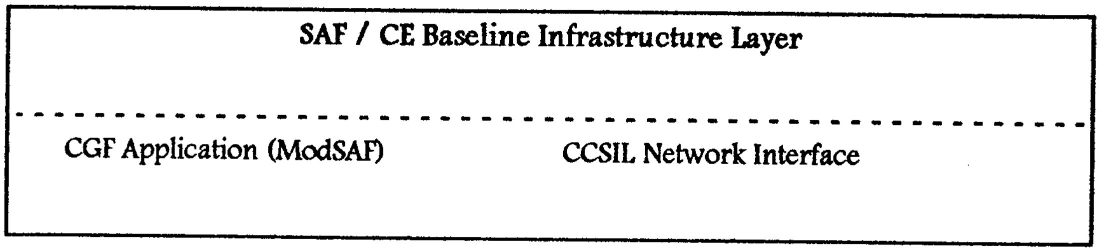

Figure 4.5 SAF/CE Baseline Infrastructure Layer Diagram

other CEs. ModSAF is an example of a CGF that can provide the baseline infrastructure layer for a simulation training exercise. (Salisbury, Seidel, et al., 1995)

4.32.4 Mission Planning

All the necessary 'how to' information that a CA needs to plan a mission is encoded as 'objects'. These objects are called Constraint Sets (CS). A CS represents a C++ class and describes how a CA makes coherent decisions. A CS specifies what decisions need to be made for a particular type of military operation and generates options for each decision. There are two types of CSs used in CA software: a component CS and a composite CS. A component CS is used to evaluate alternatives and generate a feasible solution to a single portion of the overall CA mission. Each component CS corresponds to an Army unit collective task like 'Conduct a Tactical Roadmarch' similar in principal to the FSMs used in ModSAF to represent collecti ve behaviors. Once a

component CS is instantiated, it becomes a plan for executing a specific behavior (task) given the tactical situation. A composite CS is a collection of component CSs that are linked together to form military missions similar to the execution matrix used in ModSAF. A composite CS is constructed for each individual mission that the CA is expected to execute during an exercise. (Calder, Carreiro, et al., 1996)

All CSs have a common set of characteristics. They all have a set of minimum input variables, a set of derived variables, generator functions, and prioritizer functions. Minimum input variables are pieces of information required to construct a plan for a given CS. This information is supplied to the CS when it is initially constructed and contains general information. Derived variables are pieces of information that get computed by the CS during a simulation such as tactical choices. Some examples of tactical choices are route, formation, or rate of march selections. Each derived variable has a generator and prioritizer function that corresponds to it. A generator function produces a list of values for each derived variable. These values are consistent with choices of previous derived variables and the simulation's current state. The prioritizer function orders the derived variables based on these values. The generator function can invoke the terrain and situational awareness modules and any other modules located in the CE Application layer to support relevant decisions it must make. (Calder, Carreiro, et al., 1996)

In order for a CA to generate a new plan or instantiate a composite CS, it must evaluate its current operation and examine what is necessary to accomplish the mission given by its higher headquarters. This function is performed by a class within the CA software that decomposes CCSIL messages into appropriate composite CS. This class is called a Combinatorial Constraint Satisfaction (CCS) class. It is responsible for invoking

the correct CSs during the instantiation process. It accomplishes this by mapping the military tasks contained in CCSIL messages to the most appropriate component CSs encoded in the CA knowledge base. Once these CSs are identified and generated, then a plan for accomplishing the given mission is said to be instantiated and ready for execution. The generator function assists the CCS during this process. (Calder, Carreiro, et al., 1996)

The CCS is also invoked when replanning becomes necessary. It assists the planner module in planning reactions (selecting appropriate CS) to events occuring in the CA's synthetic battlespace and for replanning the remainder of the original mission once the reaction is complete. Events that would cause a CA to plan a reaction can be the receipt of a FRAGO or other CCSIL message from a superior which orders a significant change to the current mission or encountering an unexpected situation that requires immediate action. The interface between the planner, situational awareness, and tracker modules facilitates this process by allowing the planner to become aware of the replanning criteria being met and a new plan being needed. New plans are generated in the same fashion that was discussed in the preceeding paragraphs. (Calder, Carreiro, et al., 1996)

4.33 Command Agent Review

In 1999, the Institute for Simulation and Training (IST) was tasked by the Army's Simulation, Training, and Instrumentation Command (STRICOM) to evaluate an Army Ground Command Entity (AGCE) developed by the Science Application International Corporation (SAIC). The primary purpose of the project was to investigate whether or not SAIC's AGCE were suitable for inclusion into the OneSAF

testbed, and secondarily, develop any prototype enhancements that could improve the usability and performance of the AGCE.

Since ModSAF provides the baseline for the OneSAF testbed, IST had to first integrate the AGCE software with ModSAF 5.0 so that it could compile and run. In order for this integration to occur, IST had to make some software modifications to ease installation requirements and facilitate running the AGCE. IST had to merge several common libraries that ModSAF and AGCE shared and modify AGCE software to use autoconf. Autoconf is a software architecture that provides better configuration and portability across platforms. ModSAF uses it, but AGCE software does not.

Once these modifications were made, IST then reviewed AGCE performance. During the review, IST found that the AGCE took an inordinate amount of time accessing the CFOR Environmental Utilities and performing terrain analysis. Environmental Utilities represent terrain and terrain reasoning functions in the CFOR architecture. IST developed two algorithms to improve AGCE performance. They developed an improved algorithm to test for the intersection of two line segments and developed an improved algorithm to mark areas that should not be traveled. Both improvements contributed to a significant speedup in AGCE performance.

In summary, IST was able to integrate SAIC's AGCE software into the STRICOM ModSAF baseline and provide a basis for future integration into the OneSAF Testbed. However, this integration was not easy to accomplish and future research is necessary to improve the usability and extensionability of AGCE architecture for general use. (Foss and Robinson, 1999)

4.34 Command Agent Performance Demonstration

On 25 January 2000, the Institute for Simulation and Training (IST) gave a demonstration of command agent technology. William Foss, a Computer Scientist at IST and SME on command agents, conducted the demonstration. He used a single Dell computer containing dual Pentium III 450 MHz processors, 256 MB of Random Access Memory (RAM), and Linux Redhat 6.0 as the operating system. One processor ran ModSAF while the other processor was used for the AGCE. The purpose of this demonstration was to determine if command agents could replan entity behavior based solely on observation of their battlespace, determine AGCE software functionality and ease-of-use, and interview an SME on command agents. The demonstration was conducted on Hunter-Liggett, California terrain (desert environment) and involved a friendly tank battalion conducting a planned 'Hasty Attack'. Midway through the scenario an enemy tank platoon (four vehicles) was spotted on the battalion's northeast flank. The CA controlling the tank battalion, once aware of the enemy vehicle's location, replanned the mission of one of its tank companies, ordering the tank company to 'Attack' towards the enemy platoon. In summary, the tank battalion was able to autonomously replan behavior and react to an unexpected event on the synthetic battlefield without human intervention. Unfortunately, as the simulation progressed and the tank company approached the enemy's position, a software problem prevented them from properly recognizing all four enemy vehicles.

When asked if he had encountered any problems when using AGCE software, Mr. Foss replied that he had. He gave two instances. First, he stated that because of the number and complexity of the computations that the AGCE software required frequently the system would crash. Second, he stated that the documentation used to

integrate AGCE with ModSAF was difficult to use. He felt that it needed to become more formalized with ease-of-use a major consideration.

4.35 Command Agents Summary Findings

Command agents are capable of simulating multiple commanders simultaneously of similar or different echelons or roles. They are capable of conducting planning, coordinating, communicating, monitoring and executing tasks during a simulation autonomously. Thus, they can provide a method in ModSAF to allow a friendly tank platoon employed in a counter-reconnaissance mission to autonomously replan its behavior (transition from a defensive to offensive operation) based on observation of its synthetic battlespace. It employs a constraint satisfaction approach to accomplish this with highly specialized software and a very extensive knowledge base upon which to draw cases. Unfortunately, the software that supports CA technology is still immature and unstable. Until the documentation for command agents and other CFOR CE's has been formalized and the 'bugs' worked out allowing a more stable platform on which to run the simulation, implementing CFOR technology into ModSAF for the expressed purposes of this research is not recommended. However, some technology can be transferred. The criteria that cause a CA to begin replanning new missions during simulation are similar to the reasons a real human would use in an actual tactical situation. These reasons are: the receipt of a FRAGO or other message from a superior which orders a significant change to the current mission, encountering an unexpected situation that requires immediate action, and after the completion of a reaction to an unexpected situation. Some examples of reacting to an unexpected situation would be reacting to enemy indirect fires, reacting to an enemy air attack

(helicopter or fixed wing), or executing actions on contact that were discussed in chapter 4.2. These behaviors are reactive in nature. (Calder and Chamberlain, 1998)

4.4 Close Combat Tactical Trainer Semi-Automated Forces

CCTT SAF is the software system responsible for populating the CCTT synthetic battlefield with computer controlled friendly and enemy forces. It is comprised of two primary software components; the 'SAF Workstation' which allows an operator to monitor and control CCTT SAF generated forces (friendly and enemy); and the 'CGF Simulator' which performs the behavior simulation and dynamics for CCTT SAF forces. Because this research is focused on behavior representation, the CGF Simulator will be further analyzed to determine current behavior capabilities and whether or not these behaviors can be transferred into ModSAF. Henry Marshall, an electronics engineer at STRICOM's Engineering Technology Division and SME on CCTT SAF, was instrumental in providing information for this portion of the research and answering any research related questions.

4.41 CCTT SAF Architecture

The CGF Simulator is organized around the CGF Application. The CGF Application has five software modules, which allow it to provide credible representation. These modules (illustrated in Figure 4.4 CGF Application Context Diagram) are terrain, vehicle simulation, DIS Manager, a SAF Entity Object Database (SEOD), and behavior. The terrain module is responsible for processing the terrain database and providing terrain information. It uses a CTDB format with several functional enhancements required for CCTT. The CTDB format generates an effective

representation of the synthetic terrain in terms of soil type, feature data, and elevation. The vehicle simulation module provides the physical modeling and vehicle dynamics simulation for all CCTT SAF forces. The DIS manager module is responsible for sending information on CCTT SAF entities across the DIS network. The SEOD module is a run-time database that contains command and control information that can be accessed by CCTT simulation participants. The SEOD provides the means by which the SAF Workstation and CGF Simulator communicate with each other. The behavior module is responsible for generating vehicle and unit behavior used by CCTT SAF and will be examined in greater depth. (Petty, 1995)

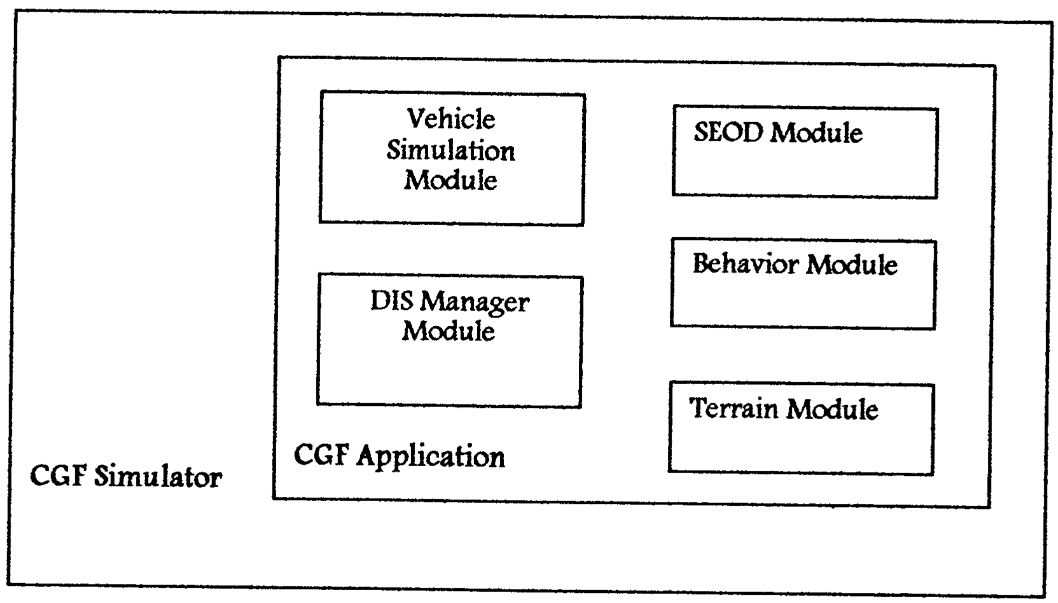

Figure 4.6 CGF Application Context Diagram

4.42 Behavior Generation

Tactical behaviors employed by CCTT SAF are governed by Combat Instruction Sets (CISs). A CIS is a natural language description of tactical behavior that is founded

and traceable to existing U.S. Army doctrine. It is derived from current training and doctrinal literature into a structured and formatted description of how a training collective task is to be performed by a particular type unit such as a friendly tank platoon. For U.S. forces, CISs are derived from U.S. Army Mission Training Plans (MTP) which contain all of the collective tasks and performance measures required of real military units such as a basic behavior, response, or battle drill. Since there is no MTP body of knowledge available upon which to base task selection or build behavioral descriptions for Opposing Forces (OPFOR), threat SMEs using available foreign military publications are used to define behavior and create OPFOR CISs. An identification label of BXXXX is designated for BLUFOR CISs and XXXX for OPFOR CISs. Once a CIS has been developed and documented, it is then translated into software as an FSM written in ADA. Currently there are 523 BLUFOR CISs and 382 OPFOR CISs. (STRICOM CCTT Interoperability Document, dated 3 March 1997)

4.43 Combat Instruction Sets (CIS)

There are five elements of a CIS. These elements are a behavior description (actions to be taken), initial and terminating conditions, input data, and situational interrupts. Behavior description details the nature of the action that an entity executes in the order that the action is to be taken. It is grouped into move, shoot, observe, or communicate which are basic battlefield functions. Initial conditions detail reasons when an entity will execute a specific behavior. Terminating conditions detail reasons for an entity to stop executing specified behavior and then what to do next. Input data is administrative information that is provided prior to run-time to coordinate and synchronize SAF movement. An example of input data would be the listing of a

specified vehicle route that the SAF is supposed to travel. Situational interrupts detail conditions that would cause an entity to execute a reactive behavior in lieu of one that was preplanned and is currently executing. (Kraus, Franceschini, et al., 1996)

Appendix B is an example of a BLUFOR CIS for a tank platoon. The collective task title is 'Assault an Enemy Position'. It is divided into five sections (A-E). Section A identifies the CIS and provides the administrative data that relates to it. Section B provides the doctrinal framework for the CIS. It gives the MTP task number, a general description of the task, subtasks, and standards, initail conditions, input data, and any special notes that might be relevant to this CIS. Section C provides a sequence of action that takes place during performance of the task in terms of move/shoot/monitor/communicate. Section D describes terminating conditions and the situational interupts that could cause a change in the CIS status. Section E is a Battlefield Operating Systems (BOS) checklist that crosschecks each battlefield function to ensure that they are employed. As is illustrated in this appendix (Section B, Step 5), the complete implementation of this one CIS requires implementation of many other CISs such as see CIS #B0022, Execute Actions on Contact, and CIS #B0030, Perform Fire and Movement. This allows software engineers to reuse existing CIS modules and code. (STRICOM CCTT Interoperability Document, dated 3 March 1997)

There are 47 CISs and 7 Battle drills or reactive behaviors that have been documented for a BLUFOR tank platoon. These CISs are found in Appendix C taken from the STRICOM CCTT Interoperability Document, dated 3 March 1997. This appendix provides the status and utilization of the CISs used to develop the behaviors of the CGF entities in CCTT. Column 1 lists the CIS Identification number (BXXXX).

Column 2 categorizes the CIS in terms of how the behavior is implemented into the simulation. These categories are:

- fully automated (A) - behaviors are controlled by computer model;
- semi-automated (S) - behaviors can be constructed by SAF operator;
- incorporated (C) - behaviors in another CIS or implemented by software utility;
- and, deferred (D) - CIS not part of current CCTT baseline.

Column 3 gives a short description of the collective task or battle drill tank platoons are expected to perform. Column 4 provides the collective task number found in the tank platoon MTP. Column 5 is the Task Performance support Code (TPSC). It describes the relative capacity of CCTT to support the performance of the specified MTP collective task. Each CIS is assigned a rating of 0-4 with a rating of '0' indicating that the task is insufficiently supported for training and a rating of '4' indicating that the task is fully supported. An expert system and tactical rule-base are used to select a CIS behavior for execution by the SAF entity, taking into account both the current battlefield situation and the SAF entity's orders. (STRICOM CCTT Interoperability Document, dated 3 March 1997)

As illustrated, separate CISs exist for the two tasks that this research is attempting to autonomously link together in ModSAF. These tasks are 'Conduct a Hasty Occupation of a Battle Position' (CIS B0025) and 'Perform an Attack by Fire' (CIS B0024). Both tasks are fully automated which means that when a SAF operator from his CCTT SAF workstation instructs the CCTT entity to perform that particular task, then a computer model is responsible for controlling its execution. Unfortunately, there is not a fully automated CIS behavior for 'Perform Tactical Planning' (MTP task number 17-3-0100) under which replanning falls. This behavior is only semi-automated,

which means that a human SAF operator is necessary to construct the behavior. (STRICOM CCTT Interoperability Document, dated 3 March 1997)

4.44 Implementation of CISs into ModSAF

In 1997, the Institute for Simulation and Training investigated ways to incorporate CCTT CGF technology into another CGF system. Specifically, the project's goal was to implement CCTT CISs into ModSAF, thus improving the interoperability between the two CGF systems. The project had three phases. The first phase consisted of thoroughly examining CCTT SAF to allow researchers to develop a better understanding of the structure and complexity of CCTT CISs. The second phase was a comparative analysis of CCTT SAF and ModSAF. The goal of this analysis was to identify the differences between the two SAF systems and provide researchers information on the level of difficulty associated with integrating their behaviors. The third phase involved implementing prototype CISs into ModSAF. To get a wide sample of behaviors, IST researchers chose to implement eight CCTT CISs into ModSAF (four BLUFOR and four OPFOR). These CISs were:

- Conduct Hasty Occupation of a Battle Position (B0025);
- React to Air Attack (B0113);
- Execute Traveling Overwatch (B0137);
- Emplace Hasty Protective Minefield (B0137);
- Conduct Fire Engagement (HVY0324);
- Assault an Enemy Position (HVY0022);
- Execute Evasive Actions (HVY0029);
- Company Assault an Enemy Position (HVY0113).

The result of this research project was the successful implementation of two CCTT CISs (B0025 and HVY0022) into ModSAF. Although IST researchers found many differences between the two systems to include differences in the C2 hierarchy, CGF services, Task Management, reactive behaviors, environment, terrain, code sharing, and crew level behaviors, they were able to make the necessary modifications to make the project successful. This is significant because it reuses CCTT SAF technology, leveraging the U.S. Army's investment in simulation, and paves the way for future interoperability between the two CGF systems. (Kraus, Franceschini, et al., 1996)

4.46 CCTT SAF Performance Demonstration

On 13 March 2000, the Science Applications International Corporation (SAIC) gave a demonstration of CCTT SAF technology. Matthew Griffin, a senior Software Engineer and SME on CCTT SAF conducted the demonstration. Since it was a forgone conclusion that CCTT SAF entities could not autonomously replan behavior, the purpose of this demonstration was to observe CCTT SAF entities executing a tactical operation. The simulation was run on a Motorola AIX system. Two computer workstations were connected via a LAN. One workstation was used to control the friendly units taking part in the demonstration and a different workstation was used to control enemy forces. A friendly tank company executed a tactical roadmarch along a pre-planned route. Midway through the operation an enemy tank platoon (consisting of three tanks) interdicted the company, engaging it with direct fires. The tank company deviated from its original mission because of this new threat and immediately returned fire upon the attacking enemy. The result was two friendly and all three enemy vehicles

destroyed. Upon the conclusion of this engagement, the tank company returned to its original mission, conduct a tactical roadmarch.

Mr. Griffin was asked what would have been the tank company's action had it known about the enemy's position prior to the engagement. For example, if a friendly scout observation post saw the enemy platoon several kilometers away from the tank company preparing for an attack and reported it. Would this alter the tank company's behavior? He stated that first CCTT SAF does not have a messaging capability between units so the information from the scout observation post would have been reported to a human operator only. The human operator would be necessary to intervene and instruct the company to deviate its behavior based on this information. Secondly, unless the tank company sighted the enemy force with sensors organic to its unit, then in all likelihood they would have continued executing their original mission since CCTT SAF entities can not autonomously replan their own behavior. Behavior can only be altered when a situational interrupt deems a reactive behavior necessary like displayed in the demonstration or when a human operator intervenes and changes the task execution matrix. The scenario was performed on terrain found at the U.S. Army's National Training Center (desert environment).

4.47 CCTT SAF Summary Findings

CCTT brings a credible and realistic portrayal of the battlefield into a synthetic environment. CCTT SAF is an integral part of this program. It is responsible for translating military doctrine into behaviors that are performed by SAF entities. CISs are a natural language description of these tactical behaviors. Unfortunately, CCTT SAF entities can not automatically respond (transition from one task to another) based on

information that they receive during the course of a simulation. A human operator is necessary to make any adjustments to task execution. Henry Marshall discusses this limitation and a workaround that was developed in his journal article titled "SAF in the CATT Systems, Update 1999". He states, "When a SAF entity receives information such as an enemy contact report or bridge report that would be challenging for SAF to automatically interrupt, the system generates an icon on the SAF operator's workstation, so the operator can redirect the entities based on their situation". Henry Marshall reaffirmed this position during an interview on 10 February 2000. In conclusion, CCTT SAF entities do not have an autonomous replanning capability that can be transferred into ModSAF.

4.5 Summary of Case Studies

Table 4.1 (developed in chapter 3) summarizes the results of this case study analysis. As has been demonstrated, a thorough literature review of each case was completed. A simulation-based demonstration of each case technology was conducted, appropriate observations were made, and interviews with SMEs on each case were completed. Bill Foss was interviewed and verified the findings on CFOR command agents and Henry Marshall was interviewed and verified the findings on CCTT SAF. DARPA's CFOR command agent technology has the autonomous replanning capability that this research project seeks and it has been integrated with ModSAF. Unfortunately, this technology focuses at the company command level and above, is unstable, and the majority of the software associated with it still lacks appropriate documentation. This would make it very difficult to implement it into a desired platoon level situation and is not recommended. However, some techniques used from command agents can be

transferred (see Table 4.2). The criteria used in CFOR command agent technology that causes an entity to autonomously replan its behavior, transitioning from one task to another, should be transferred. These criteria form the basis for the constraint sets and match what was found during the literature review of military publications and later validated by a military SME. These criteria are:

1) Receipt of a FRAGO or other message from a superior which orders a significant change to the current mission;
2) Encountering an unexpected situation that requires immediate action such as an enemy contact report;
3) Upon completion of a reaction to an unexpected situation where reactive behaviors have been invoked.

CCTT SAF does not have a CIS for autonomous replanning, but instead prompts the operator with an icon telling him that a significant event in the simulation has occurred and needs his intervention. Since ModSAF already integrates this type technique with

Case	Literature Review Completed	Demonstration Observed	SME Interview	Replanning Capability	Ease of Transfer	Other Techniques & Technology Transfer
Command Agents	Yes	Yes	Yes	Yes Constraint Sets	Difficult	Replanning Criteria
CCTT SAF	Yes	Yes	Yes	No Icon prompt to SAF operator	Similar Technique exists in ModSAF	Combat Instruction Sets

Table 4.2 Case Study Summary Information

text message prompts; there is nothing available to transfer. However, the CISs found in CCTT SAF for 'Conduct a Hasty Occupation of a Battle Position' and 'Perform an Attack by Fire' should be transferred. These collective behaviors contain more detail

than ModSAF's behaviors. They are tailored for specific unit types such as a BLUFOR tank platoon, which makes CISs more attractive than the collective behaviors found in ModSAF and a better fit for the purposes of this research. ModSAF collective behaviors are generic in nature. Both BLUFOR and OPFOR entities execute the same collective task in the same manner.

4.6 Recommendation

A new behavioral model must be constructed that uses technology from both case studies. The criteria used by command agents to begin the replanning process (focusing on the receipt of an enemy contact report) should be incorporated and the CISs for the tactical tasks that the platoon is prepared to execute in a counter-recon operation incorporated. These tasks are a 'Hasty Occupation of a Battle Position' and 'Perform an Attack by Fire'. Combining information from these two case studies will result in a realistic, effective, and useful behavioral FSM. The intent for this next section is to provide a detailed description of the battlefield functions in order to allow a programmer to construct a more useful FSM for inclusion in ModSAF. This is illustrated in Figure 4.7 below.

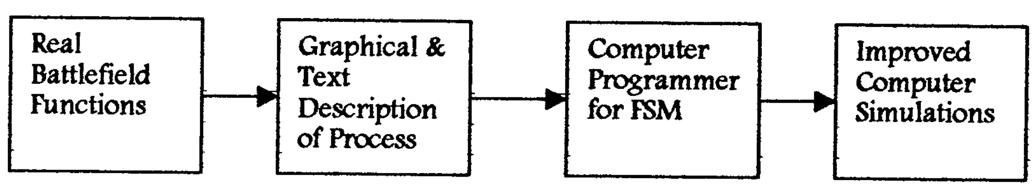

Figure 4.7 Making Battlefield Functions a Simulation Reality

4.7 Proposed Finite State Machine

For simplicity, the scenario developed in chapter 1.51 and illustrated in Figure 1.6 will be used in the design of a replanning FSM. It is assumed that the tank platoon is conducting a 'Hasty Occupation of a Battle Position' vicinity grid PK120400 in its assigned sector of a company counter-reconnaissance zone. There is a scout Observation Post (OP) forward of the tank platoon's position vicinity grid PK125420 with observation to the platoon's forward boundary. The platoon has three pre-planned routes that it can use to intercept and destroy enemy vehicles forward of its position if necessary. These routes are numbered 1, 2, and 3. An enemy recon vehicle has entered the platoon's sector and appears to be heading towards a prominent piece of terrain vicinity grid PK100360 to establish an OP. The purpose of the OP is to allow enemy observation of friendly defensive preparation. The enemy vehicle has temporarily halted at grid PK105410. Friendly artillery and mortar fires are unavailable to provide supporting indirect fires unless the target description is three or more stationary vehicles. The friendly scout OP has sent an enemy contact report to the tank platoon with the following information, "One stationary enemy recon vehicle located grid PK105410". Although there are many collective tasks that could be employed to destroy this vehicle, the platoon leader chooses to perform an 'Attack by Fire'.

There is a sequence of 11 steps (Table 4.1 page 52) that a tank platoon leader uses when he receives a report or order from an external source to the platoon and decides whether or not to act upon the information contained in it. Since the goal for this research project is to propose an operational model (illustrated in Figure 4.8 page 86) for implementing a replanning behavioral FSM into ModSAF, dispensation will be

made to describe in its entirety the platoon leader's actions when a decision is made to act. Captain (CPT) Chris Norrie, an Armor officer currently assigned as a tank company commander with 1st Battalion, 8th Cavalry Regiment Fort Hood, Texas, validated this operational model during an interview on 22 March 2000. CPT Norrie has over 8 years experience in armored/mechanized tactics. Additionally, he restated what COL James Nunn had said during his interview that this flow of action that a platoon leader uses does not always happen sequentially. Included in this model will be the need for the platoon leader to plan a new route. Specific reasons for transitioning from one state to another are given in Table 4.3 (State Transition Matrix) on page 87.

The first step in this process is the receipt of a communiqué that could affect the platoon's current state (mission). This communiqué could be a Situation Report (SITREP) from an adjacent unit, an enemy contact report, or an order changing the platoon's mission. For our purposes, this communiqué is an enemy contact report sent to the platoon from the scout observation post located in front of it. Contact reports are usually preformatted and include target size and description, activity, location, and time of observation. One such report used by the Army is the SALUTE report [S-size, A-activity, L-location, U-Unit, T-time, and E-Equipment (enemy)]. The report is usually communicated by radio.

Upon receipt of the enemy contact report, the tank platoon leader must evaluate and assess its impact on his current mission. This is the basis for step 2. When assessing the report's impact, the platoon leader must decide between one of three alternatives. Alternative 1 is a decision to remain in his current state (defending his battle position). There are three causes for the platoon leader to return to his original state:

1) The contact report is irrelevant, providing no impact on his operation (enemy vehicle is not in his sector);
2) Contact report does not require the platoon leader's immediate attention (enemy vehicle just entered sector and poses no immediate threat);
3) Higher echelon headquarters wants the platoon to continue monitoring the situation before taking any offensive action.

The sequence of steps for this alternative would be steps 2-1 or 2-9-1. Alternative 2 requires the platoon leader to act on the information contained in the report or else risk mission failure. In this alternative, it is assumed that the enemy vehicle is located along one of the platoon's pre-planned and rehearsed routes. In this instance, the tank platoon leader would immediately initiate movement and perform its be-prepared-mission (Attack by Fire). The sequence of steps for this alternative would be steps 2-10-11. Alternative 3 (most difficult) requires the platoon leader to act upon receipt of the contact report, but requires him to modify his original plan. The sequence of steps for this alternative would be 2-3. Regardless of which alternative is employed, the platoon leader is obligated to periodically inform his higher headquarters about events taking place in his area of responsibility. This notification can take place prior to the execution of an operation or upon its conclusion.

Based upon the premise that the original plan must be modified (alternative 3), then the platoon leader's next step (step 4) is to analyze the terrain in his area of operations. He should pay particular attention to key terrain that could support an ABF position with unobstructed observation and fields of fire for his force and the avenues of approach through sector that the enemy might take. It is imperative that the platoon leader knows his location (PK120400), the location of the enemy (PK105410), and the expected location where the enemy is moving (PK100360) when conducting this analysis. The analysis should be made using the five military aspects of terrain, which

are obstacles, avenues of approach, key terrain, observations and fields of fire, and cover and concealment. The platoon leader should identify:

- Locations of natural and manmade obstacles that impede or stop military movement and determine how they might affect his unit and the enemy;
- Advantageous avenues of approach through sector that can be used by both the platoon and enemy forces;
- Key terrain that affords a marked advantage to the unit that can seize or control it;
- Positions from which the platoon can effectively observe and engage the enemy or vice versa. Usually, the best observation is obtained from the highest terrain features in the area and the best fields of fire are those areas that provide the greatest distances between weapon and target;
- Routes and areas that provide concealment from observation such as woods, trees, or underbrush and cover from direct fire.

The platoon leader can advance directly from this step to either step 5 or 6.

Step 5 in this sequence is for the platoon leader to search and select the most advantageous terrain from which he would like to attack the enemy. This ABF position must allow the platoon to engage and destroy the enemy using long-range direct fires or using the standoff of the tank's main gun or engage the enemy at a distance that is greater than his weapon systems. This requires the platoon leader to know the maximum effective ranges for his weapons and his foes. The ABF position should be between 200 and 1000 meters wide to accommodate all four tanks. If terrain constraints dictate, one section of tanks (two) can be positioned at one location and the other section at another, as long as they can mutually support each other. It might be necessary for the tank platoon leader to get approval from another unit for a proposed ABF location. This can be accomplished by the platoon leader coordinating directly with the unit in question or by asking his higher headquarters to coordinate for him.

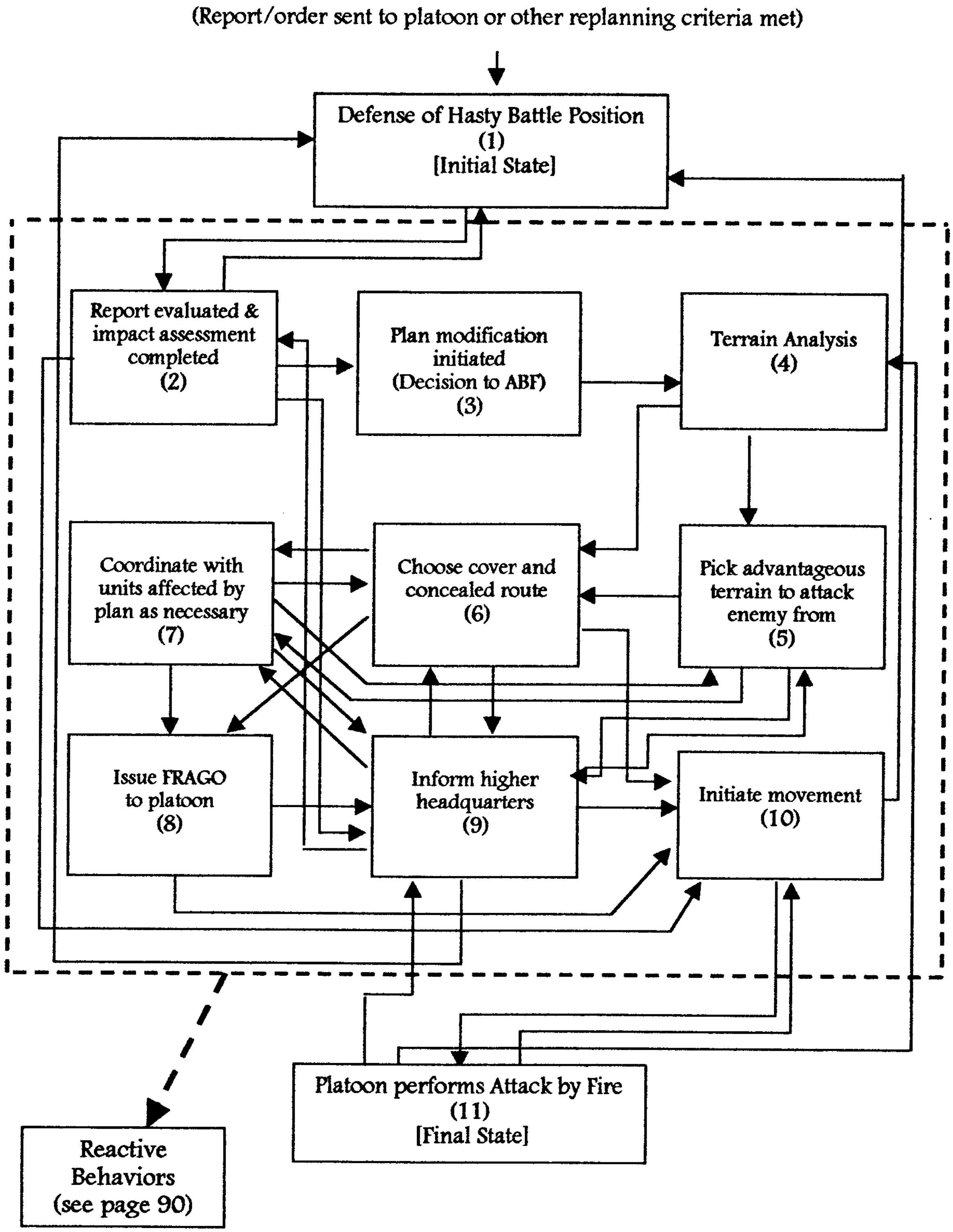

Figure 4.8 Process Flow Diagram for Proposed FSM

Cases involving direct coordination will follow the sequence of steps 5-7-5. Cases where the platoon leader requires assistance will follow the sequence of steps 5-9-5. Upon this step's conclusion, the platoon leader will advance to step 6.

Current State	Next State	Reason for Transition to Next State
1	2	Report received
2	1	Not in Platoon's Area of Operations (no impact)
2	3	In Platoon's Area of Operations (yes impact)
2	9	Inform higher headquarters of impact and intent
2	10	Attack criteria met
3	4	Activity completed
4	5	Activity completed
4	6	Covered and concealed route needed for movement
5	6	Activity completed
5	7	Direct coordination for land use necessary
5	9	Coordination by higher headquarters for land use necessary
6	7	Activity completed
6	8	Coordination for land use not needed, FRAGO ready to issue
6	9	Coordination by higher headquarters for land use necessary
6	10	Route selected (no coordination necessary) ready to initiate movement
7	5	Direct coordination for land use completed
7	6	Direct coordination for land use completed
7	8	Activity completed
7	9	Coordination for land use completed
8	9	Activity completed
8	10	Ready to initiate movement
9	1	Unit ordered to remain in BP
9	2	New report or order issued
9	5	Coordination for land use completed
9	6	Coordination for land use completed
9	7	Coordination for land use initiated
9	10	Activity completed
10	1	Return to original location along planned route
10	11	Activity completed
11	4	New route needed
11	9	Inform HQs mission complete/awaiting new instructions
11	10	Prepared to move along a pre-planned route

Table 4.3 State Transition Matrix

Step 6 in this sequence calls for the platoon leader to search and select a route from his current location to the proposed ABF location. The platoon leader should try to select a route that keeps in low ground as much as possible and avoids traveling along the top of ridgelines and over hilltops. This route should provide concealment from enemy observation and if possible cover from direct fires. Existing road networks can be utilized. If the platoon leader does not need to coordinate his route with any other units, then he can advance to step 8. Cases involving coodination with another unit (request to travel through their sector) follows the sequence of steps 6-7. Cases where the platoon leader requires assistance from his higher headquarters to coordinate a route on his behalf will follow the sequence of steps 6-9-6-8.

Step 7 in this process (if applicable) is for the tank platoon leader to coordinate with any friendly units that may be affected by his proposed mission. Coordination would be given via radio communication and would include at a minimum current enemy situation, concept of the new operation with the grid for proposed ABF location, routes that will be utilized, the proposed start/end of the operation, and requests for assistance. In this scenario, the tank platoon leader would have to coordinate with the scout observation post that is located to his front. Upon completion, the platoon leader will advance to step 8.

Step 8 is the issuance of a FRAGO to members of the tank platoon. This can be communicated in person or by radio. The FRAGO should contain at a minimum an updated enemy or friendly situation, the new mission (task and purpose), the scheme of maneuver (how the mission will be conducted), and any other relevant information that is necessary to accomplish the mission. Figure 4.9 illustrates a sample platoon FRAGO for this operation. Upon the conclusion of this step, the platoon leader could

advance directly to step 9 (inform higher headquarters about operation) or step 10 (initiate movement) if higher headquarters has already been notified.

> "Scouts have identified an enemy recon vehicle vicinity grid PK105410."
>
> "Our mission is to perform an Attack by Fire to prevent enemy forces from bypassing our location and identifying the extent of our main defensive preparation."
>
> "We will move in a platoon wedge down Route Blue to an ABF position vicinity grid PK111413. We will initiate movement in 15 minutes."
>
> "Questions"

Figure 4.9 Sample Tank Platoon FRAGO

Step 9 is informing the next higher echelon headquarters of the planned operation if it has not already done so. This notification would be communicated by radio in a SITREP, pre-formatted to meet operational requirements. The SITREP would contain at a minimum the same information contained in the FRAGO plus would include the platoon's strength (four tanks) and the expected time of departure/return. If the platoon leader feels that his unit is incapable of performing the mission or requires assistance, he would ask for it at this time. The platoon leader's higher headquarters could decide to scratch the proposed mission leaving the platoon to remain in its current state (return to step 1) or propose a different mission which would require the platoon leader to return to step 3 to begin the process over again. Step 10 is the initiation of tactical movement along the proposed route. Speed, movement techniques, and movement formations should be given in the FRAGO and should maximize the platoon's battle space and minimize gaps and dead space between

vehicles. The platoon should back away from its hasty battle position when it initiates tactical movement.

The final step in this sequence is to perform the new task (Attack by Fire against the enemy recon vehicle). In executing this task, the platoon should continue to use tactical movement to get into positions that allow it to employ its weapons at its maximum effective ranges for tank main gun or as terrain dictates. At all times during the conduct of mission planning the platoon should be prepared to react to the following battlefield situations:

- React to Indirect Fire
- React to Enemy Air Attack
- React to Nuclear, Biological, and Chemical Attack
- React to Contact.

These reactions or battle drills are automatic responses to situations in which immediate and violent execution of an action is vital to the platoon's safety or mission success. They should be executed at the tank crew level with minimal instructions and thought processes. In ModSAF these behaviors are reactive in nature and should be included as subtasks.

By default upon the completion of step 11, the platoon leader should notify his higher headquarters about the recently completed mission and then return to its original state. Two alternatives can be employed to return the platoon back to its original location. Alternative 1 is for the tank platoon leader to return to step 10 and retrace the same route that was just used to conduct the attack (sequence 11-10-1). Alternative 2 is for the platoon leader to analyze the terrain and select a new route to get back to its original position using the sequence of steps 11-4-6-10-1. In some extenuating circumstances, the platoon might be ordered to conduct a new mission

from its current location. In this instance, the platoon leader would employ the sequence of steps 11-9-2 where it would begin replanning its next mission.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND FUTURE RESEARCH

5.1 Final Summary

Simulations provide an opportunity for United States military leaders to utilize current training methodology to train themselves and their staffs for wartime missions at minimum cost. An essential component of a simulation is the Computer-Generated Force (CGF) that populates the synthetic battlefield with simulated entities. One technique for replicating this force is to use a computer system that generates and controls multiple simulation entities using specialized software and/or a human operator. A CGF is intended to behave like the actual force that it represents. Automated behaviors may allow entities to react autonomously to events unfolding on the simulated battlefield and/or to orders given to them by a human operator. Behaviors are encoded using various approaches such as production rules, algorithms, or formal behavior specifications that attempt to replicate realistic human cognitive processing and physical behaviors. Although there are many different CGFs in existence today, this thesis focused on how ModSAF replicates and implements human behavior.

This research identified that currently there is no organic behavioral model in ModSAF that allows an entity to conduct self-modification of tasks (replan) based purely on its observation of the synthetic battlefield. A human operator sitting at a

computer workstation is necessary to make behavioral decisions for subordinate computer generated entities. This does not represent how a military leader would conduct these tasks in an actual tactical situation. Currently a company commander taking part in a simulated combat operation does not have to contend with any of the friction found in many real world operations. From his computer workstation, the company commander inputs the instructions for each of his subordinate platoon leaders. By default, the system allows the company commander to provide perfect information and intelligence to the battalion commander and his staff on the events unfolding in their particular areas of responsibility. This allows a battalion commander and his staff to make more informed decisions based on wholly accurate information; a capability that does not exist in actual tactical situations. To avoid these unrealistic situations, an ability to self-modify or autonomously replan behavior in the context of the overall mission is necessary to be replicated in simulation.

In order to provide more credible human behavioral representations, this thesis proposed an operational model that when implemented will enable the inclusion of more autonomous behaviors into ModSAF. A case based research approach was used to examine two CGF-related applications currently used by the United States Army to see if any technology could be transferred into the proposed model. These two applications were CCTT SAF and DARPA's CFOR command agents. After an extensive literature search, capability demonstration for each case, and interviews with SME's for both cases, it was determined that CCTT SAF does not have an embedded replanning capability and that command agents do. Unfortunately, the computational and financial cost for implementing command agents for lower echelon military decision-makers would be extensive. However, some technology was transferable into the

proposed replanning FSM. The criteria used by command agents to begin the replanning process were incorporated into the proposed behavioral model. Additionally, a recommendation was made to implement the CCTT CISs for the tactical tasks that the platoon is prepared to execute in a counter-recon operation into ModSAF later.

Army SMEs were used to validate the criteria to replan a unit's behavior, how the replanning would occur, and the operational model that illustrates the actual replanning steps complete with interdependencies between steps. COL James Nunn validated why and how a tank platoon leader would replan his unit's mission (page 52) and CPT Chris Norrie validated the operational model (page 85).

5.2 Conclusions

The proposed operational model for a replanning FSM can and will make more useful and credible behavioral representations of lower echelon leaders in ModSAF. It forms the basis for a new reactive behavior 'React to Situation Change' that will bring into a training environment some of the friction found in actual combat, enabling military commanders and their staffs to train for their wartime mission in a realistic manner. Although this FSM was tailored towards a specific tactical scenario (a counter-recon operation) and how a unit transitions from one tactical task to another autonomously in that scenario, it could be extended to encompass many other unit collective tasks currently found in ModSAF. This is evident because the actual replanning occurs in the area encapsulated within the dashed box on page 86. For instance, the tasks 'Conduct a Tactical Roadmarch' and 'Destroy an Inferior Force' could be linked together [one as the initial state (step 1) and one as the final state (step

11)] so that a tank platoon could transition between tasks autonomously without human intervention. This would greatly enhance the capabilities of the CGF, providing an overall better simulation training exercise to its users.

Unfortunately, financial resources necessary to outsource the coding required to bring the model to reality limited the original scope of this research.

5.3 Future Research

Obviously, this thesis only proposes an operational model for a replanning behavioral FSM to be implemented in ModSAF. Several areas could be exploited to build upon this model and enhance ModSAF. The next logical step would be to transition the operational model to appropriate models found in Unified Modeling Language by Grady Booch, James Rumbaugh, and Ivar Jacobson (1999). After that one could code the behavioral FSM and then implement it into a ModSAF tactical scenario for validation and verification. A recommendation would be to use the tactical scenario developed in Chapter One of this thesis as the baseline test case and that the replanning FSM link the two collective tasks "Hasty Occupation of a Battle Position' and 'Perform an Attack by Fire'. This effort would need the talents of a talented ModSAF software engineer.

After the replanning FSM has been verified and validated, then this capability could be extended to linking other collective tasks together and enhancing the behaviors of OPFOR entities. A more autonomous, capable CGF in a small, exportable package would be invaluable to tactical commanders and their staffs during the decision-making process. A more autonomous OPFOR could allow the battalion staff to rehearse their different courses of action for any given tactical operation against a

'thinking' opponent. This could be accomplished prior to the real world execution of the tactical operation and could prevent the battalion from executing an ill-conceived plan. Only minimal overhead support would be required to make this a reality since today's personal computers are powerful enough to run ModSAF.

Until the Army releases ONESAF, it might be beneficial to implement additional CISs from CCTT SAF into ModSAF. CISs provide a more credible representation of collective behaviors than those currently integrated in ModSAF. These CISs could be implemented using the same techniques demonstrated by scientists at IST and would further enhance ModSAF as a constructive simulation.

APPENDIX A

GLOSSARY

AAFSM- Asynchronous Augmented Finite State Machines

ACR- Advanced Concepts Requirements.

AI- Artificial Intelligence.

AMC- Army Material Command.

ATGM- Anti-Tank Guided Missile.

BN - Battalion.

C2- Command and Control.

C3I- Command, Control, Communication, and Information.

CCTT- Close combat tactical trainer--a U.S. Army virtual simulation.

CGF- Computer Generated Forces.

COA- Course of Action.

DFD- Department of Force Development.

DOD- Department of Defense.

DOTLOMS- Doctrine, training, leadership, organization, materials, and soldiers.

FM- Field Manual.

FSM- Finite State Machine.

IST- Institute for Simulation and Training at the University of Central Florida.

M&S- Modeling and Simulation.

ModSAF- Modular Semi-automated Forces.

MTP- Mission Training Plan

OneSAF- Next generation military SAF.

RDA- Research, Development and Acquisition domain in military M&S.

S1- Military personnel staff officer

S2- Military intelligence staff officer.

S3- Military operations staff officer.

S4- Military logistics officer.

SA- Situational Awareness.

SAF- Semi-automated Force.

SME- Subject Matter Expert.

STRICOM- Simulation, Training, and Instrumentation Command (U.S. Army command).

TEMO- Training, Exercises, and Military Operations domain in military M&S.

TOC- Tactical Operations Center.

TRADOC- Training and Doctrine Command.

TTP- Techniques, Tactics, and Procedures.

APPENDIX B

CCTT SEMI-AUTOMATED FORCES (SAF) COMBAT INSTRUCTION SET (CIS)

SECTION A. IDENTIFYING AND ADMINISTRATIVE DATA

1. CIS ID #: B0031
2. DATE PREPARED OR UPDATED: 10/4/93
3. CIS TITLE: ASSAULT AN ENEMY POSITION
4. TYPE UNIT: Tank Platoon
5. RELEVANT ENTITIES/PLATFORMS: Tank, M1A1/M1A2
6. NAME OF PREPARER: I. Jacobs PHONE NO.: 703/734-5994
7. APPROVING GOVERNMENT AGENCY: TSM-CATT
8. DATE APPROVED: 04 April 1994
9. NAME OF APPROVING OFFICIAL: Ralph W. Briggs, MAJ AR, SAF Project Officer

SECTION B. DOCTRINAL FRAMEWORK FOR CIS

1. REFERENCES:
ARTEP 17-237-10-MTP; FM 17-15; FM 17-12-1; FM 71-1; FM 7-7J; FM 101-5-1
2. ARTEP TASK AND NUMBER: Assault an Enemy Position (17-3-0220)
3. GENERAL DESCRIPTION OF TASK:
An assault is the culmination of an attack that closes with and destroys the enemy; it is the actual overrunning and seizing of an occupied enemy position. Normally, the assault force is composed of tanks and infantry elements under the control of the company team commander. The assault force moves by fire and movement (see CIS #B0030) along covered and concealed routes to the flanks or rear of the enemy position until it reaches the assault position (the last covered and concealed position before the o bjective). Typically, tanks lead, with BFVs following to protect against dismounted infantry and provide suppression to the flanks. Once the commander has determined that all observed tanks and antitank weapons on the objective have been destroyed or suppressed, he orders the assault. The assault elements move rapidly in a line formation, under cover of direct and indirect fires, to the objective, moving through it to the far side. Infantry dismounts to mop up resistance and clear the objective. (FM 17-15, pp. 3-28, 3-29; FM 7-7J, p. 2-88; FM 71-1, p. 3-26; FM 101-5-1, p. 1-6)
4. ARTEP SUBTASKS AND STANDARDS: (ARTEP 17237-10-MTP, pp. 5-81 to 5-84)
1. PL plans assault and directs platoon's movement to assault position:
   a. PL issues FRAGO (I)
   b. PL determines last covered and concealed position that platoon can occupy before beginning assault (D)
   c. PL determines best covered and concealed route to this position (D)
   d. PL orders platoon to move along the rout e to this position (I)
2. Once platoon reaches last covered and concealed position, tank crews prepare for assault:
   a. Tanks come on line while remaining in covered and concealed positions (V)
   b. Tanks scan Threat position to determine Threat size and type, location of mines and obstacles, and route of assault to objective (V)
   c. Platoon conducts last-minute ch ecks of weapons, vehicles, equipment (N)
   d. TCs report to PL when ready to assault (N)
   e. Each tank remains in hide position until ordered to assault (N)
3. PL collects and reports tactical information on Threat situation at objective:
   a. Determines if objective will be defensible or undefensible by platoon after assault

(D)

b. Determines size and type of Threat force and locations of mines and obstacles, and selects best route for the element to assault into flanks of Threat's defe nses whenever possible (D)

c. Makes estimate of situation to determine additional courses of action required prior to assault (D)

d. Informs commander of situation with complete SPOTREP, and requests supporting direct and indirect fires be massed on known or suspected Threat locations immediately prior to assault (I)

4. PL immediately orders the element to assault upon receiving order from company team commander:

a. Platoon assaults in line formation to allow maximum firepower to front (V) [NOTE: If assault is part of company team obstacle breach, platoon, rapidly and without stopping, moves in column formation along lane created by breach force and moves back o n line after clearing obstacle.]

b. Platoon maintains forward momentum along assault route(s), in conjunction with other company team elements (V)

c. Platoon employs all weapon systems to defeat Threat in detail and destroys or suppresses all resi stance on objective (V)

d. PL requests the lift/shift of supporting direct and indirect fires as necessary (I)

e. Platoon moves to hull-down positions on objective to prevent cresting or skylining of vehicles if objective is defensible (V)

f. Platoon sweeps through objective to occupy defensible terrain beyond it if objective is not defensible (V)

g. PL initiates indirect fires to suppress known or suspected Threat forces on or within range of objective (V)

5. PL or PSG coordinates with supporting and adjacent units as platoon approaches objective:

a. Coordinates with base-of-fire element(s) to lift or shift direct fires in front of platoon's movement (I)

b. Coordinates with adjacent element(s) and dismounted infantry to destroy specific targets, bunkers, machine gun nests, or pockets of Threat resistance (I)

c. PL lifts and shifts indirect fires beyond objective (D)

6. Platoon completes actions on objective:

a. Platoon consolidates objective (if defensible) or next defensible terrain beyond objective to secure the position and prepare for counterattack (V)

b. PL reports to commander once position is secured (I)

c. Platoon conducts reorganization activ ities (V)

5. INITIAL CONDITIONS:

a. Platoon is operating as part of company team attack or counterattack, and company team commander has ordered platoon to assault OPFOR position.

b. OPFOR is no larger than platoon size in hasty defensive positions.

c. Platoon has completed actions on contact (see CIS #B0022, Execute Actions on Contact, and CIS #B0030, Perform Fire and Movement).

d. A base-of-fire element (another element of the company team) is positioned to support platoon's assault.

e. Platoon is in last available position before moving to assault position.

6. INPUT DATA:

a. Designate location of platoon at commencement of this CIS (see 5.e above).
b. Designate location of assault position.
c. Specify platoon's route and formation from present position to assault position.
d. Specify location of enemy force (i.e., the objective), to include location of mines and obstacles.
e. Specify scheme of maneuver from assault position to objective:
(1) Platoon's route
(2) Time of departure from assault position (on actual battlefield, this occurs when enemy has been suppressed or destroyed). [NOTE: The platoon pauses only momentarily in the assault position.]
f. Designate primary fighting positions that platoon's tanks are to occupy on or forward of objective, depending on whether or not objective is defensible (see discussion in 7 below).
g. Designate location of base-of-fire element.
h. Designate TRPs (may use fire support overlay).

7. NOTES:

a. Section C.1 below mentions defensible and non-defensible objectives. A defensible objective is one that offers all or most of the following characteristics: positions that afford long-range observation and fields of fire (to or near the maximum effective ranges of tank and BFV weapons systems); terrain that shields enemy observation and fires; adequate space laterally (400-700 meters, depending on METT-T) and in depth to accommodate primary, alternate, and supplementary positions for the platoon's tanks; covered and concealed, hull-down fighting positions, with covered and concealed routes of ingress and egress; mutually supporting positions; natural and man-made obstacles. (FM 17-15, pp. 4-3 thru 4-7, 4-12; IDT judgment)
b. Figure 1 depicts a hide position. Figure 2 depicts actions on the objective when it is defensible, and figure 3 when it is not defensible (see discussion in C.1 below). Figure 4 shows tanks supporting by fire while infantry assaults.
c. Refer to Appendix A, Tank Platoon Default Parameters.

SECTION C. ACTIONS TO BE TAKEN

1. SEQUENCE OF ACTIONS:

1. PL plans assault and directs platoon's movement to assault position:

a. PL issues FRAGO (I)

Platoon internal communication not implemented in SAF. Minimum information required by SAF operator includes following elements: enemy situation, location of base-of-fire element, platoon mission, objective, location of assault position, time of depart ure from assault position, route to objective, formation, and actions on objective. [NOTE: These are all input data.] (FM 17-15, pp. 2-3 to 2-4, A-2 to A-3, A-10; IDT judgment)

b. PL determines last covered and concealed position that platoon can occupy before beginning assault (D)

Input data — see B.6.b above.

c. PL determines best covered and concealed route to this position (D)

Input data — see B.6.c above.

d. PL orders platoon to move along the route to this position (I)

COMMUNICATE: PL issues order to move from present position along designated

route to assault position. (FM 17-15, p. 3-28; IDT judgment)
[NOTE: The ARTEP omits any requirement to actually move from the present position to the assault position. However, since there is a requirement to issue the order to do so, it is assumed that actual movement is also required. Refer to CIS #B0030, Per form Fire and Movement, which covers movement of the platoon to the assault position.]

2. Once platoon reaches last covered and concealed position, tank crews prepare for assault:

a. Tanks come on line while remaining in covered and concealed positions (V)
MOVE: Tanks form on line, in hide positions,1 in assault position (see figure 1). (FM 17-15, pp. 3-28, 3-29, and 4-14)

b. Tanks scan Threat position to determine Threat size and type, location of mines and obstacles, and route of assault to objective (V)
SEARCH/OBSERVE: Each tank establishes search pattern from about 10 o'clock to 2 o'clock (12 o'clock is direction of objective), overlapping with the tank on its left or right. (FM 17-15, p. 2-19; IDT judgment) [NOTE: Information on enemy, mines and o bstacles, and route to objective is input data.]

3. PL collects and reports tactical information on Threat situation at objective:

a. Determines if objective will be defensible or undefensible by platoon after assault (D) SAF operator responsibility.

b. Determines size and type of Threat force and locations of mines and obstacles, and selects best route for the element to assault into flanks of Threat's defenses whenever possible (D) SAF operator responsibility. Also input data — see B.6.d and e above.

c. Makes estimate of situation to determine additional courses of action required prior to assault (D) SAF operator responsibility.

d. Informs commander of situation with complete SPOTREP, and requests supporting direct and indirect fires be massed on known or suspected Threat locations immediately prior to assault (I)

COMMUNICATE:

(1) PL informs commander of enemy situation from assault position immediately prior to assault. (ARTEP 17-237-10-MTP, p. 5-82)

(2) PL requests supporting indirect and direct fires be massed on known or suspected enemy locations on or within range of objective immediately prior to assault (use TRPs — see B.6.h above). (FM 17-15, p. 3-29; ARTEP 17-237-10-MTP, p. 5-82)

SHOOT:

(3) Indirect fires are massed on known or suspected OPFOR locations immediately prior to assault (see 3.d(2) above). (FM 17-15, pp. 3-28 and 3-29)

(4) As platoon leaves assault position, indirect fires are shifted beyond and to flanks of objective (to block enemy routes of withdrawal) (use TRPs — see B.6.h above). (FM 17-15, pp. 3-28 and 3-29; FM 71-1, p. 3-26; IDT judgment)

4. PL immediately orders the element to assault upon receiving order from company team commander:

a. Platoon assaults in line formation to allow maximum firepower to front (V)
[NOTE: If assault is part of company team obstacle breach, platoon, rapidly and without stopping, moves in column formation along lane created by breach force

and moves back o n line after clearing obstacle.], and
b. Platoon maintains forward momentum along assault route(s), in conjunction with other company team elements (V)

MOVE:

(1) Platoon departs assault position and assaults rapidly in line formation to allow maximum firepower to front. (FM 17-15, pp. 3-28 and 3-29)

(2) If assault is being conducted as part of company team obstacle breach, platoon, when reaches obstacle, changes formation to column, traverses breached lane, and reverts to line formation on far side. (FM 71-1, pp. 3-41 to 3-42) [NOTE: Default condi tion will not be assault during breaching operation. For actions at obstacle, see CIS #B0036.]

c. Platoon employs all weapon systems to defeat Threat in detail and destroys or suppresses all resistance on objective (V)

SHOOT: Enroute to objective, tanks engage enemy targets while on the move or at temporary halts. Tanks use preferably machine guns for suppressive fire.2 (FM 17-15, p. 3-29; FM 17-12-1, p. 7-7)

d. PL requests the lift/shift of supporting direct and indirect fires as necessary (I)

COMMUNICATE: (See also E.2 below)

(1) PL requests lifting/shifting of supporting indirect and direct fires, as necessary, during assault; coordinates with base-of-fire element to lift or shift direct fires in front of platoon's movement (use TRPs — see B.6.h above). (FM 17-15, p. 3-27; IDT judgment)

(2) As approaches objective, lifts and shifts indirect fires (use TRPs — see B.6.h above). (FM 17-15, p. 3-27; IDT judgment)

e. Platoon moves to hull-down positions on objective to prevent cresting or skylining of vehicles if objective is defensible (V)

MOVE: (1) If objective is defensible, platoon occupies hull-down positions on objective. (FM 17-15, pp. 3-29 to 3-31. Also see figure 2 and item B.6.f in input data above.)

(2) During sweep of objective, tanks do not crest or skyline on high ground to avoid fires of antitank weapons that may be on reverse slope or in depth. (FM 17-15, p. 3-29)

SHOOT:

(3) If tanks are prevented from reaching defensible positions by hasty minefields, they support by fire from covered positions while infantry assaults and clears objective (see figure 4). (FM 17-15, p. 3-30)

f. Platoon sweeps through objective to occupy defensible terrain beyond it if objective is not defensible (V)

MOVE: If objective is not defensible, platoon sweeps across objective and occupies defensible positions beyond (on far side of) objective. (FM 17-15, p. 3-29. Also see figure 3 and item B.6.f in input data above.)

g. PL initiates indirect fires to suppress known or suspected Threat forces on or within range of objective (V)

COMMUNICATE: PL calls for indirect fires on likely/suspected enemy positions within range of objective (use TRPs — see B.6.h above). (FM 17-15, p. 4-21)

5. PL or PSG coordinates with supporting and adjacent units as platoon approaches objective:

a. Coordinates with base-of-fire element(s) to lift or shift direct fires in front of platoon's movement (I)
SAF operator responsibility.
b. Coordinates with adjacent element(s) and dismounted infantry to destroy specific targets, bunkers, machine gun nests, or pockets of Threat resistance (I) SAF operator responsibility.
c. PL lifts and shifts indirect fires beyond objective (D)
See 4.d(2) above.
6. Platoon completes actions on objective:
a. Platoon consolidates objective (if defensible) or next defensible terrain beyond objective to secure position and prepare for counterattack (V)
MOVE/SEARCH/OBSERVE: (1) Platoon consolidates on objective (see CIS #B0025, Conduct Hasty Occupation of Battle Position, and CIS #B0029, Consolidate and Reorganize). (FM 17-15, pp. 3-32 to 3-33)
(2) During and after occupation of objective, tanks orient gun tubes and weapons in general direction of enemy and likely avenues of approach to the battle position. Tanks maintain constant observation to front (generally from 10 o'clock to 2 o'clock, b ut this may vary based on factors of METT-T) using unaided vision, optics, and night/reduced visibility devices. (ARTEP 17-237-10-MTP, p. 5-112; IDT judgment)
SHOOT:
(3) Once on objective, tanks engage fleeing enemy or counterattack forces. (FM 17-15, p. 3-29)
b. PL reports to commander once position is secured (I)
COMMUNICATE: PL informs company team commander of platoon's status. (FM 17-15, p. 3-33)
c. Platoon conducts reorganization activities (V)
COMMUNICATE: Platoon reorganizes on objective (see CIS #B0025, Conduct Hasty Occupation of Battle Position, and CIS #B0029, Consolidate and Reorganize). (FM 17-15, p. 3-33)
2. TIME-DEPENDENT ACTIONS/RESULTS:
If enemy has been in defensive positions more than 8 hours, hasty minefields can be expected. (FM 17-15, p. 3-30)

SECTION D. CHANGES IN CIS STATUS

1. SITUATIONAL INTERRUPTS:
a. If, in the context of this CIS, the OPFOR that the platoon is assaulting is armed with tanks and/or ATGMs that are within effective range, this CIS takes precedence over any situational interrupts. (IDT judgment based on "most dangerous" target criter ia in FM 17-12-1, pp. 3-14 to 3-16)
b. If, in the context of this CIS, the OPFOR that the platoon is assaulting is armed with tanks and/or ATGMs that are not within effective range, or OPFOR is not armed with tanks and/or ATGMs:
(1) Intervening contact with OPFOR armed with tanks and/or ATGMs and within effective range takes precedence, and the platoon will execute the appropriate action drill (CIS #B0009, B0010, B0011, or B0012). (FM 17-15, p. 3-18)
(2) Platoon will react to indirect fires (CIS #B0013). (FM 17-15, p. 3-21)
(3) Platoon will take active AD measures while moving or stationary, as

appropriate (CIS #B0019 or B0020). (FM 17-15, pp. 3-22 and 3-23)
c. If platoon encounters obstacle, execute CIS #B0036, Take Actions at Obstacle. (FM 17-15, pp. C-1 to C-2)
2. TERMINATING CONDITIONS:
a. Objective is secured, i.e., tanks have assumed designated positions and sectors of fire on objective.
b. Directed change of mission.

SECTION E. BATTLEFIELD OPERATING SYSTEMS (BOS) CHECKLIST

1. MANEUVER:
2. FIRE SUPPORT:
Coordination of indirect fire support in the assault, between PL and FIST (through company team commander), is continuous from prior to initiation of assault until after objective is secured. SAF operator uses TRPs to call for fire if must go through FIS T/company team commander. Format is as follows:

ELEMENT	EXAMPLE COMMAND
Identification	"(Platoon call sign)
Warning Order	Fire for effect
Target Location	Grid. Coord. (or target #, shift known point)
Target Description	"Three enemy tanks"
Method of engagement	NA
Method of fire/control	NA

3. AIR DEFENSE:
4. COMMAND AND CONTROL:
5. INTELLIGENCE:
6. MOBILITY/COUNTERMOBILITY/SURVIVABILITY:
See CIS #B0036, Take Actions at an Obstacle.
7. COMBAT SERVICE SUPPORT:
1 Covered and concealed positions, situated behind firing positions, that may have to be occupied when concealed firing positions are not available. (FM 17-15, p. 4-14) 2 Direct fire placed on known or likely enemy locations to degrade one or more of his basic combat functions: moving, shooting, observing, or communicating. (FM 17-12-1, p. 7-7).

APPENDIX C

LISTING OF COMBAT INSTRUCTION SETS (CIS) FOR A BLUFOR TANK PLATOON

This appendix provides the status and utilization of the CISs used to develop the behaviors of the CGF entities in CCTT. These CISs are categorized as follows:

- fully automated (A) - behaviors are controlled by computer model
- semi-automated (S) - behaviors can be constructed by SAF operator
- incorporated (C) - behaviors in another CIS or implemented by software utility
- deferred (D) - CIS not part of current CCTT baseline.

(Taken from the STRICOM CCTT Interoperability Document, dated 3 March 1997)

CIS ID	Category	Description	Task ID	TPSC
B0002	A	Execute a Staggered Column formation	17-3-0204	3
B0003	A	Execute a Line Formation	17-3-0207	3
B0004	A	Execute a Wedge Formation	17-3-0205	3
B0006	A	Execute a Vee Formation	17-3-0206	3
B0008	A	Execute a Herringbone Formation	17-3-0202	2
B0009, 0010, 0011, 0012	A	Action Drill – Left, Right, Front, Rear	Drill 2	3
B0013	A	React to Indirect Fires	Drill 5	2
B0014	A	Contact Drill	Drill 3	2
B0015	A	Execute Traveling	17-3-0209	3
B0016	A	Execute Bounding Overwatch	17-3-0211	3
B0017	A	Execute Traveling Overwatch	17-3-0210	3
B0018	A	Perform Assembly Area Activities	17-3-0200	1
B0019	A	Take Active AD Measures While Moving	44-3-C002	2
B0020	A	Take Active AD Measures While Stationary	44-3-C002	2
B0021	A	Conduct Tactical Road March	17-3-0212	3
B0022	A	Execute Actions on Contact	17-3-0221	4
B0024	A	Perform an Attack By Fire	17-3-0219	4
B0025	A	Conduct Hasty Occupation of Battle Position	17-3-0227	3
B0026	A	Occupy a Platoon Battle Position	17-3-0222	2

CIS ID	Category	Description	Task ID	TPSC
B0027	A	Perform a Passage of Lines	17-3-0215	2
B0029	A	Consolidation and Reorganization	12-3-C021	1
B0030	A	Perform Platoon Fire and Movement	17-3-0217	4
B0031	A	Assault an Enemy Position	17-3-0220	4
B0032	A	Execute a Platoon Defensive Mission	17-3-0225	3
B0036	A	Take Actions at an Obstacle	17-3-0401	4
B0041	A	Perform Resupply Operations	17-3-0601	3
B0001	C	Execute a Column Formation	17-3-0203	3
B0005	D	Execute Echelon Formation	17-3-0208	3
B0007	D	Execute a Coil Formation	17-3-0201	2
B0023	S	Perform Reconnaissance by Fire	17-3-0218	4
B0028	S	Assist a Passage of Lines	17-3-0214	1
B0033	C	React to Enemy Dismounted Attack	17-3-0224	3
B0035	S	Assist a Relief in Place	17-3-0226	3
B0037	D	Execute a Prepared Obstacle	17-3-0402	0
B0038	D	Construct a Hasty Obstacle	17-3-0403	1
B0039	D	Emplace a Hasty Protective Minefield	17-3-0404	0
B0040	S	Move in a Built-up Area	17-3-0213	4
B0042	D	Perform Maintenance Operations	17-3-0603	1
B0043	C	Establish an Observation Post	17-3-0302	0
B0044		Move Thru a Defile	17-3-2020	
B0045		Conduct Breach Force Operations	17-3-3070	
B0046		Conduct Assault Force Operations	17-3-3080	
B0047		Conduct Support Force Operations	17-3-3090	
	C	Change of Formation Drill	Drill 1	3
	C	Air Attack Drill	Drill 4	3
	C	Take Passive AD Measures	44-3-C001	1
	C	Employ Command & Control Measures	17-3-0105	4
	C	Employ Camo & ECM Measures	17-3-0301	0

CIS ID	Category	Description	Task ID	TPSC
	S	Perform Tactical Planning	17-3-0100	4

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